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ISDN INTERNET ENVIRONMENT AND STANDARDS ANALYSIS

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This research project presents background information on the current state-of-the-art in ISDN technology, and provides advice for implementing the new ISDN technology into existing communication systems. It covers ISDN and network standards, a general approach to internetworking, and a detailed analysis of ISDN-LAN and ISDN-DDN internetworking problems.

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ISDN INTERNET ENVIRONMENT AND STANDARDS ANALYSIS

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1. INTRODUCTION

The following paper prepared by the IGIS Research Team at the University of Arizona's Computer Engineering Research Lab is the Final Report on the subject of ISDN-Internet Environment and Standards Analysis. The intent of this report is to present background information on the current state of the art in ISDN technology, and to provide advice for implementing the new ISDN technology into existing Army communication systems. This information will be presented in Chapters two through six of this report, beginning with general information about ISDN and network standards, general approach to internetworking, and finally discussing the specific cases of ISDN-LAN and ISDN-DDN internetworking problems.

The term ISDN, Integrated Services Digital Network, refers to a concept in communications technology rather than a particular type of hardware. ISDN can be thought of as a world-wide information system that uses international standards to deliver a broad range of services (voice, data, video, etc.) which are all integrated into a single end-to-end digital network. The concept of an ISDN has been around for a couple of decades, and now because of standardization and technological advancements in digital communications this concept is becoming a realization.

Development of standards for ISDN is the underlying key to its success. A dedicated effort by CCITT, International Telephone and Telegraph Consultative Committee, along with a handful of other organizations, has resulted in a set of ISDN

standards, CCITT Red Book, I-Series Recommendations. These standards were first released in 1984 and a revised and expanded version is expected to be released in 1988. The 1984 ISDN standards were primarily directed toward the user-network interface. This allowed many vendors to begin participating in the development of ISDN equipment such as: switches, terminals, as well as an assortment of VLSI chips for ISDN.

The evolution of ISDN technology is occurring at a rapid pace. Throughout the world ISDN has undergone many trials, and is actually in small scale operation in West Germany. Within the next year several other countries are expected to make ISDN services available to large customers. The United States is lagging behind other nations in the implementation of ISDN because unlike other countries, the U.S. does not have a centralized provider of communications. The European countries have government controlled Postal, Telephone, and Telegraph companies (PTT's). Within the United States there is heavy competition between companies (AT&T, GTE, Northern Telecom, etc.) for the ISDN market and therefore these companies are unwilling to take big financial risks during the early stages of ISDN development. Despite this cautious approach taken by U.S. companies, there are several field trials currently being conducted across the U.S., and customers in the U.S. can expect an operational ISDN within the next two or three years. The initial ISDN customers will be large companies, and as ISDN matures and becomes more economical the market will expand into use by small companies and will eventually migrate into use by

residential customers. The DoD, and specifically the U.S. Army, will be one of the large customers of ISDN. This requires that the U.S. Army be prepared for the coming of ISDN in order to put this technology to use as soon and effectively as possible. This report will present advice on how the power of ISDN can be tapped to enhance existing Army communication systems.

The following is a brief overview of the succeeding chapters in this report. Chapter 2 is a discussion of the necessary background information regarding standardization, the ISO-OSI Seven Layer Reference Model, and the correspondence of ISDN and Internet protocols to those standards. Chapter 3 discusses the ISO-OSI Internetworking Model. Chapter 3 also contains some information relative to ISDN-LAN gateways. Chapter 4 is "Methodology for Computer Network Internetworking." This chapter provides information pertaining to the general case of internetworking two networks. The topics discussed in Chapter 4 include: general gateway model, generic gateway functions, four internetworking approaches, and a comparison between the four approaches. The comparison of the four internetworking approaches is made from a practical point of view taking into consideration factors such as: time, cost, complexity, and feasibility. Chapters 5 and 6 expand on the general internetworking problem presented in Chapter 4 to the specific internetworking problems of ISDN-LAN and ISDN-DDN respectively.

Chapter 5 is "ISDN-LAN (TOP or MAP) Gateway Design." The approach to developing an ISDN-LAN (TOP or MAP) gateway is based on the general principles and procedures of the Integrated

Gateway Design discussed in Chapter 4. We also use the paper "Army Implementation of ISDN" by Joseph J. Rudiger as the guideline of the ISDN-LAN (TOP or MAP) gateway design. Because TOP and MAP protocols as well as ISDN protocols are considered standard, there will be several VLSI chips, communication adapter cards, and software available to the gateway designer. The vendor products can and should be used to make the gateway design and implementation as simple as possible. We must assume that the upper four layers are compatible between the ISDN side of the gateway and the TOP or MAP side of the gateway. This implies that the ISDN-(TOP or MAP) gateway is confined to the lower three layers. Several of the generic gateway functions are related to network management, and therefore applying ISO and CCITT protocols and network management concepts to the more complex internetworking environment is a good topic for future study.

Chapter 6 presents an approach to internetworking DDN with an ISDN. The approach presented is to design and build an integrated gateway. The general case of this approach is contained in Section 4.3.3 of this report. The integrated gateway will have a four-layer DDN side and a three-layer ISDN side. Because DDN is a long-haul network, it is required that the fourth layer, Transmission Control Protocol, be added in order to handle connection control and to increase the reliability of the integrated gateway. A complete discussion of the implementation of generic gateway functions and procedures is discussed in Chapter 6.

2. BACKGROUND

2.1 ISO-OSI and CCITT Seven-Layer Reference Model

The International Organization for Standardization (ISO) organized its Technical Committee 97 (TC-97) on Information Processing Systems. The TC-97 established a SubCommittee 16 (SC-16) on Open Systems Interconnection (OSI). SC-16's task was to develop a reference model that would provide an architecture to serve as a basis for all future development of standards for world-wide distributed information systems. The International Telegraph and Telephone Consultative Committee (CCITT) also welcomed the ISO effort and appointed a special rapporteur to maintain close liaison and to apply the OSI architecture to CCITT applications.

In May 1983 the OSI Seven-Layer Reference Model (Figure 2.1) finally resulted in the approval of ISO International Standard 7498 (ISO/IS 7498) and CCITT Recommendation X.200. The ISO also defined standards at each of the OSI seven layers. According to the status of standardization process, the ISO documents of communication protocols can be: Draft Proposal (DP), Draft International Standard (DIS), or International Standard (IS). Both ISO and CCITT support the OSI direction of developing one set of international standards as the best possible resolution of incompatibilities. An example of this is the increasing cooperation between ISO and CCITT through the mutual publication of identical standards.

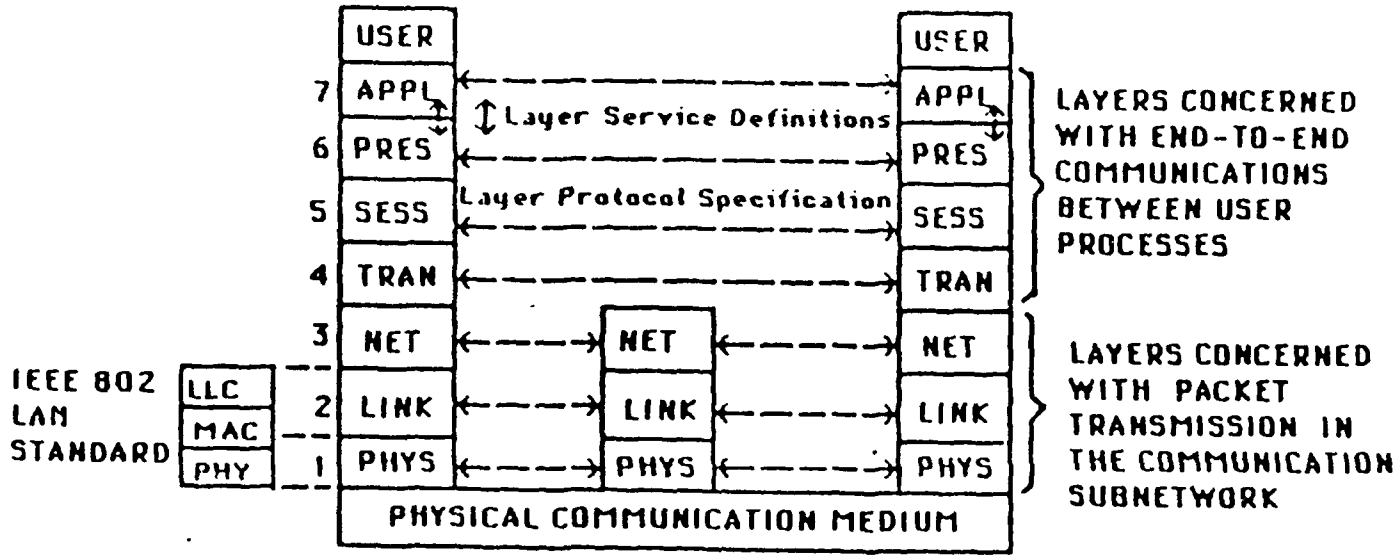


Fig. 2.1. OSI Seven-Layer Reference Model

2.2 LAN Protocols: MAP and TOP

The protocols for Local Area Networks (LAN's) are very confusing. A lot of LAN's use vendor's proprietary protocols which are not ISO-OSI compatible. The IEEE 802 Committee published LAN-802 standards: 802.2 Logical Link Control (LLC), 802.3 CSMA/CD, 802.4 Token Bus, 802.5 Token-Ring. However, the IEEE 802 standards cover only the two lowest OSI layers: layer-2 Data Link layer and layer-1 Physical layer.

During November 1980, General Motors (GM) formed the Manufacturing Automation Protocol (MAP) task force to investigate and identify common communications standards for factory systems. The factory systems comprise: programmable controllers, numerical controllers, robotic controllers, vision systems, and data terminal equipment (including hosts, minicomputers, and workstations). The Technical and Office Protocols (TOP) were developed by the Boeing Co. to address the communications problems for engineering and general office applications. Both MAP and TOP are seven-layer protocols. The MAP Version 2.1 and TOP Version 1.0 are shown in Figure 2.2. MAP and TOP choose the protocols of each of the OSI seven layers from the ISO-OSI standards. The major differences between TOP and MAP are at OSI Layer-1 and Layer-7. At Layer-1, TOP employs the IEEE 802.3 CSMA/CD baseband bus standard; and MAP employs the IEEE 802.4 Token Passing broadband bus. At Layer-7, TOP functions are for the exchange of electronic-mail messages, editable text, and graphics; but MAP functions are for exchange of information and commands between factory programmable devices.

Layer	TOP Version 1.0 Protocols	MAP Version 2.1 Protocols
7	ISO FTAM (DP) 8571 File Transfer, limited file management (ASCII and binary data only)	ISO FTAM (DP) 8571 File Transfer Protocol Manufacturing Messaging Format Standard (MMFS) Common Application Service Elements (CASE)
6	Null* (ASCII and binary encoding)	
5	ISO Session (IS) 8327 Session kernel, full duplex	
4	ISO Transport (IS) 8073 Class 4	
3	ISO Internet (DIS) 8473 Connectionless and for X.25-Subnetwork dependent convergence protocol (SNDCP)	
2	ISO Logical Link Control (DIS) 8802/3 (IEEE 802.2) Type 1, Class 1	
1**	ISO CSMA/CD (DIS) 8802/3 (IEEE 802.3) CSMA/CD media access Control, 10Base 5	ISO Token-passing bus (DIS) 8802/4 (IEEE 802.4) Token-passing bus media access control

* A null layer provides no additional services but exists only to provide a logical path for the flow of network data and control

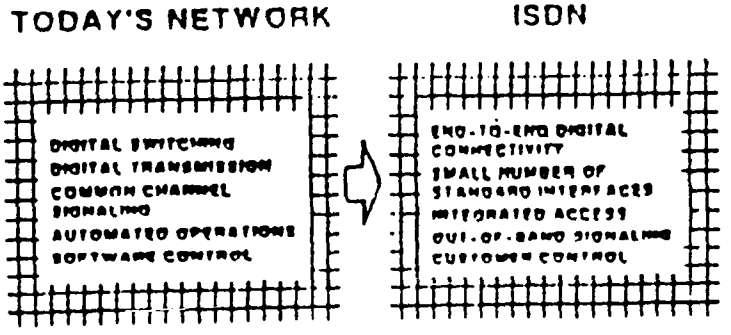
** ISO is considering moving the IEEE defined media access control (MAC) sublayer of the data link layer (Layer 2) to the physical layer (Layer 1)

Fig. 2.2. MAP Version 2.1 and TOP Version 1.0

2.3 ISDN Standard

The ISDN (Integrated Services Digital Network) is coming of age as a world-wide telecommunication revolution. This is evidenced in three areas: International standards, trials, and equipment development. The CCITT 1984 Plenary approved the ISDN standards which represent a major detailed technical advance towards the realization of ISDN. The major telecommunication providers have scheduled ISDN trials. The major telecommunication equipment manufacturers have made a commitment to ISDN products. IC chip manufacturers are working to build the underlying key to economical and compatible ISDN implementation. The public telephone networks world-wide are currently undergoing a rapid phase of evolution from analog telephony networks to Integrated Digital Networks (IDNs) and, in the future, to ISDN. Figure 2.3 shows the evolution from public networks to ISDN .

IEEE published several special issues on ISDN and related technologies [6 -- 12]. The definition of Integrated Services Digital Network (ISDN) can be viewed from two parts: Digital Network and Integrated Services. The term "Digital Network" in ISDN is defined as: digital switches, digital transmission, digital telephones with coder/decoder (Codec), and end-to-end digital connectivity. The term "Integrated Services" in ISDN is defined as: services of voice, data, image; integrated access with small number of standard user-network interfaces; out-of-band signaling (D channel and Common Channel Signaling System #7 (CCSS #7)), narrowband ISDN (Basic Access Rate and Primary Access Rate), and broadband ISDN (135 Mbit/s).



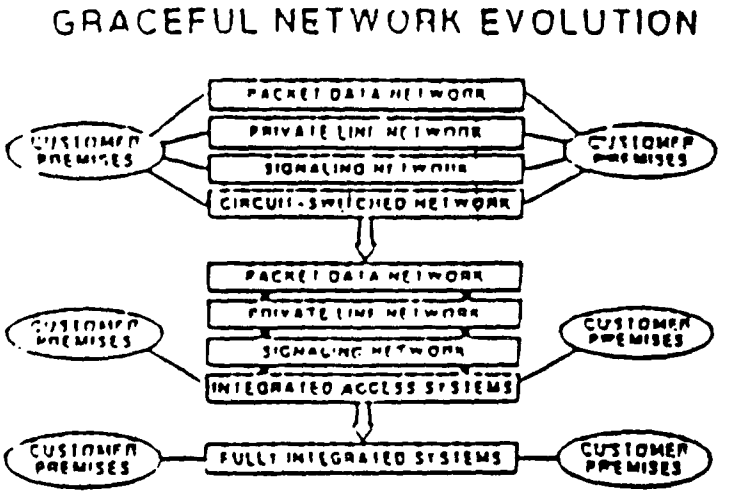


Fig. 2.3. The Public Networks to ISDN Evolution

The CCITT 1984 ISDN I-Series Recommendations are:

1. I-100 Series: ISDN Concept, Modeling, Evolution;
2. I-200 Series: ISDN Service Capabilities;
3. I-300 Series: ISDN Overall Network Aspects and Functions;
4. I-400 Series: ISDN User-Network Interfaces;
5. I-500 Series: ISDN Internetworking Interfaces;
6. I-600 Series: ISDN Maintenance Principles.

Figure 2.4 shows user-network interfaces in ISDN. The definitions of ISDN user-network interface functions are explained as follows:

1. Network Termination 1 (NT1): T interface.
   Functions are broadly equivalent to Layer-1 (physical) of the OSI model. They include:
   * Line Transmission and Termination;
   * Layer-1 line maintenance functions and performance monitoring;
   * Timing;
   * Power Transfer;
   * Layer-1 multiplexing;
   * Interface termination including multidrop termination employing Layer-1 contention resolution.

2. Network Termination 2 (NT2): S interface
   Functions are broadly equivalent to Layer-1, Layer-2, and Layer-3 of the OSI model. They include:
   * Layer-2 and Layer-3 protocol handling;
   * Layer-2 and Layer-3 multiplexing;
   * Switching;
   * Concentration;
   * Maintenance Functions; and
   * Interface termination and other Layer-1 functions.

3. Terminal Equipment (TE):
   Functions include Layer-1 and higher layers of OSI model. They are:
   * Protocol handling;
   * Maintenance functions;
   * Interface functions;
   * Connection functions to other equipments.

4. Terminal Equipment Type 1 (TE1):
   They include TE functions with an interface that complies with the ISDN user-network interface recommendations.

5. Terminal Equipment Type 2 (TE2):
   They include functions belonging to TE1 but with an interface that complies with Non-ISDN Interface Recommendations (e.g., the CCITT X-Series Recommendations) or interfaces not included in CCITT Recommendations.

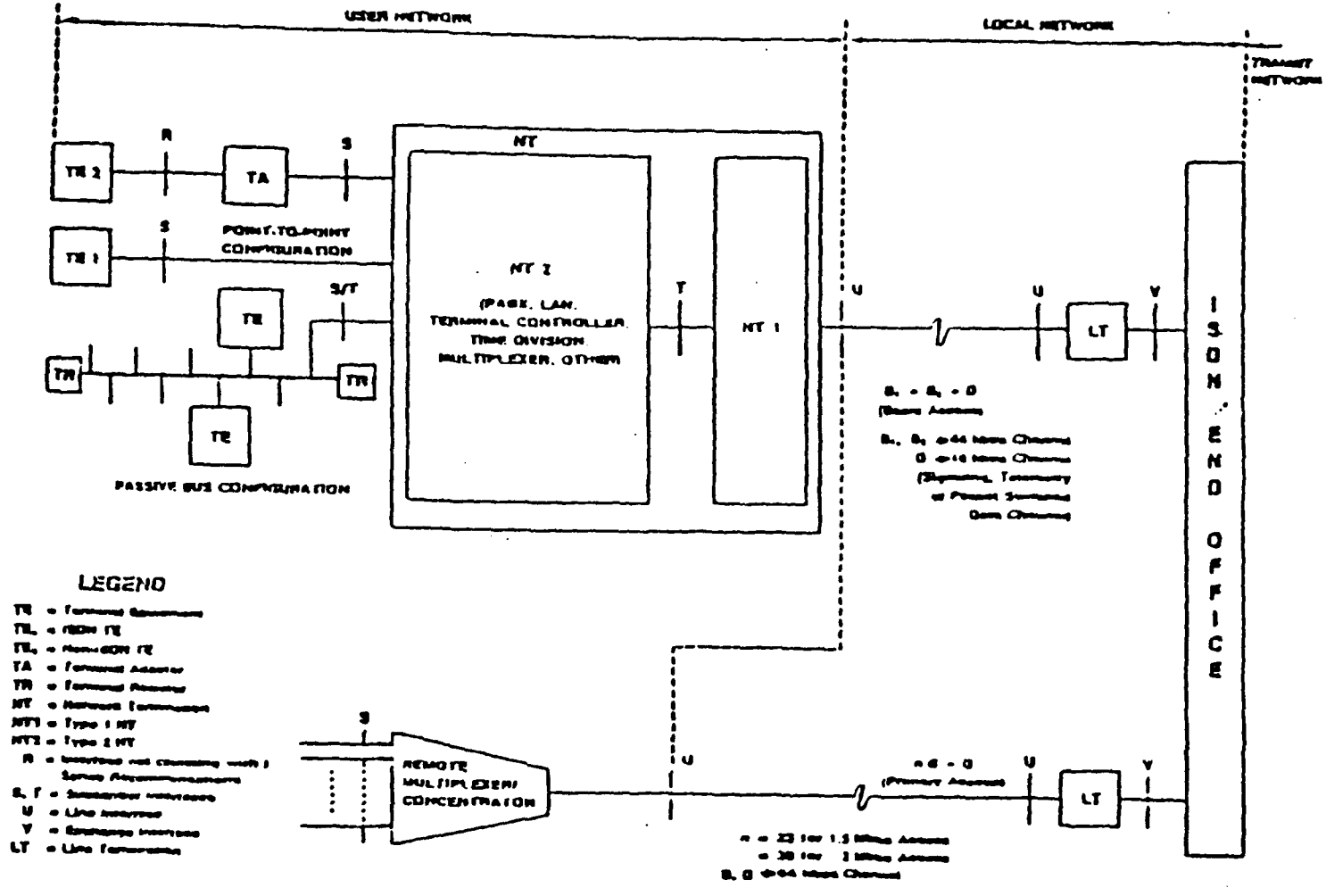


Fig. 2.4. User-Network Interfaces in ISDN

6. Terminal Adapter (TA): R interface.
   TA allows a TE2 terminal to be served by an ISDN User-Network Interface.
   TA functions broadly belong to Layer-1 and higher layers of the OSI model.

ISDN provides integrated voice, data, and image services in one network. Because LANs are for high bandwidth transmission or special purpose applications, e.g., MAP and TOP, ISDN and LANs will coexist. We will discuss ISDN-LAN internetworking in the following sections.

3. ISDN-LAN INTERNETWORKING

The CCITT and ISO both accepted the OSI Seven-Layer Reference Model. The CCITT cooperates with ISO in developing communication protocol standards and in the mutual publication of identical standards. So the discussion of the "ISDN-LAN Internetworking" will be based on the "ISO-OSI Internetworking Model of End-Systems and Subnetworks."

3.1 ISO-OSI Internetworking Model of End-Systems and Subnetworks

In a single network, the OSI Layer-4 Transport Layer provides the "End-to-End" reliable transmission services; and the OSI Layer-3 Network Layer provides the "intra-network routing function" to route the packets from source node to destination node. In the case of internetworking multiple subnetworks, the OSI Layer-4 Transport Layer still provides the "End-to-End" reliable transmission services; however, the OSI Layer-3 Network Layer is subdivided into two sublayers 3L and 3H. The Sublayer-3L provides the "intra-network routing function" within each of the subnetworks; and the Sublayer-3H provides the "inter-network routing function" to route the packets between subnetworks.

Figure 3.1 illustrates the ISO-OSI Internetworking Model of End-Systems and Subnetworks. In this model, the assumptions are:

1. The communication protocols of End-Systems A and B are compatible from layer-4 to layer-7. The layer-4 to layer-7 are end-to-end layers.

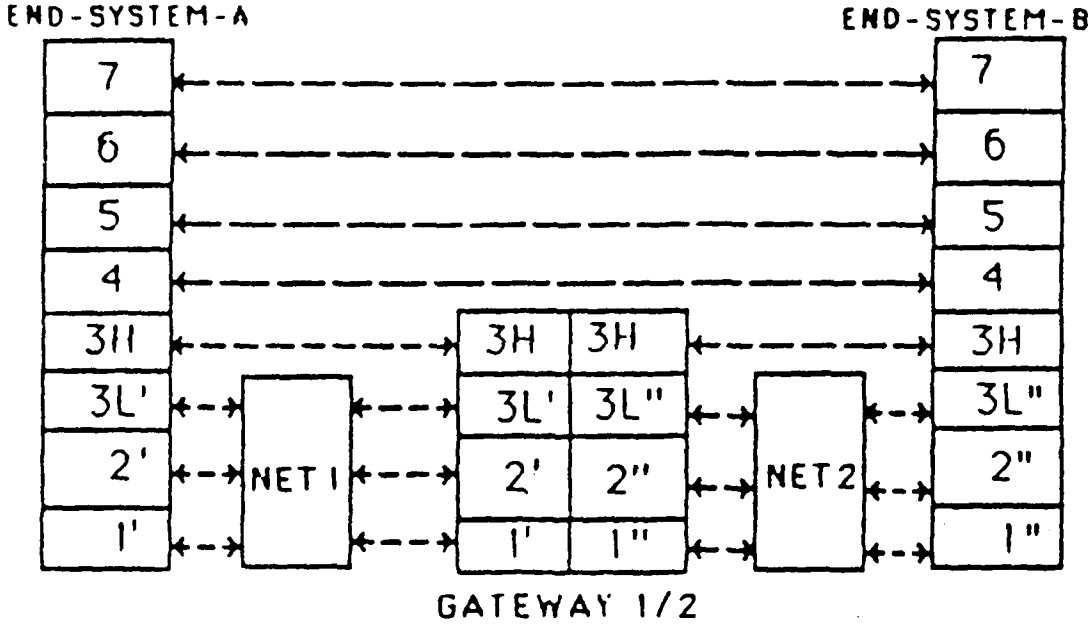


Fig. 3.1. ISO-OSI Internetworking Model of End-Systems and Subnetworks

2. The intra-network routing function within each of the subnetworks, e.g., Net1, Net2, is handled by the lower part of the Network Layer (Sublayer-3L).

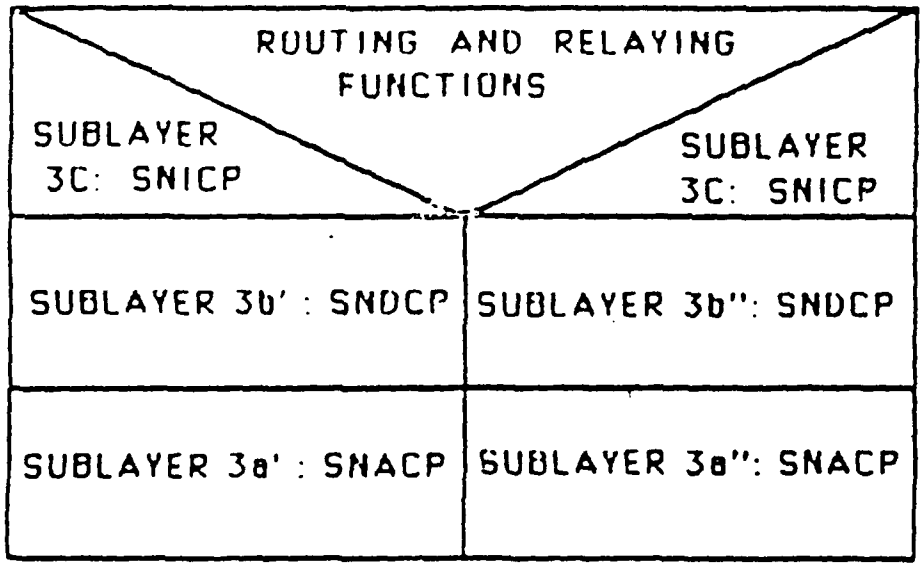
3. The inter-network routing function between different subnetworks is handled by the upper part of Network Layer (Sublayer-3H).

4. In this model, the Sublayer-3H can be: (i) ISO-IP or DDN-IP for connectionless gateways; (ii) ISO-X.25 PLP for connection-oriented gateways. The IP is Internet Protocol. The X.25 PLP is X.25 Packet-Level Protocol.

Based on different technologies and topologies, the subnetworks will be different in the lower three OSI layers. For example, X.25 packet switched networks use X.21 in the physical layer, LAPB in the data link layer, and X.25 Packet-Level Protocol in network layer. The common bus LAN's, e.g., Ethernet or Token Passing Bus LANs, use IEEE 802 protocols in physical layer and data link layer. Because no routing function is needed in the common bus topology, the network layer of common bus LANs becomes a null layer. To resolve the differences of the lower three OSI layers and to provide uniform OSI Network Layer Services to the Layer-4 Transport Layer, the CCITT and ISO agreed on a "Refined Network Layer Model" which comprises three sublayers 3a, 3b, and 3c.

The Refined Network Layer Model is shown in Figure 3.2. The three sublayers of the network layer are:

(i) Sublayer-3a: the SubNetwork ACcess Protocol (SNACP). The SNACP protocol is the specific subnetwork's internal network



SNACP: SubNetwork ACess Protocol

SNDCP: SubNetwork Dependent Convergence Protocol

SNICP: SubNetwork Independent Convergence Protocol

Fig. 3.2. The Three-Sublayer Network-Layer Model

layer protocol. It conveys the network layer functions needed to meet the requirements of the specific subnetwork such as X.25 or LANs. It handles the intra-network routing function.

(ii) Sublayer-3b: the SubNetwork Dependent Convergence Protocol (SNDCP). The SNDCP protocol is required to make up the differences between the services provided by Sublayer-3a and Sublayer-3c. It adjusts upward or downward the services provided by the Sublayer-3a SNACP.

(iii) Sublayer-3c: the SubNetwork Independent Convergence Protocol (SNICP). The SNICP protocol constitutes an internetwork protocol and accomplishes the inter-network routing function. The collective purpose of Sublayer-3b: SNDCP and Sublayer-3c: SNICP protocols are, conceptually, to mask the peculiarity of each constituent subnetwork in order to provide uniform OSI Network Layer Services through the internetworking system of the concatenated subnetworks. Figure 3.3 illustrates a scenario of internetworking based on the three-sublayer Network Layer Model.

3.2 ISDN's viewpoint of LAN

In Figure 2.4, from the ISDN point of view, the LAN is included in the Network Termination 2 (NT2). Figure 3.4 shows the same scenario of ISDN's viewpoint of LAN. The logical diagram of this viewpoint is shown in Figure 3.5. In Figure 3.5, the LAN is connected to the ISDN through the "T interface of ISDN" ; and the LAN users will connect to the LAN via the "S interface of ISDN." T provides an interface at the physical layer; and S covers the network layer, the data-link layer , and the physical layer. In this case (see Figure 3.5), the S interface will make any ISDN

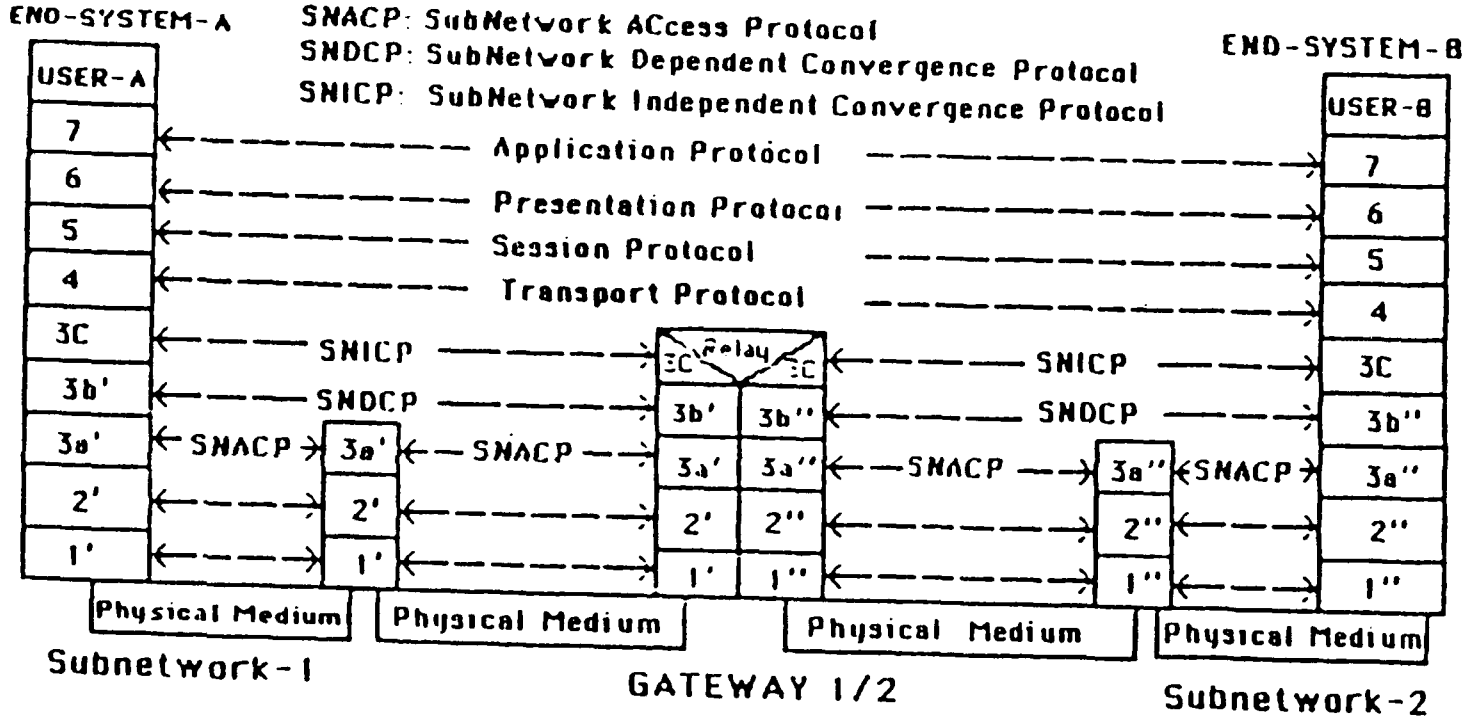


Fig. 3.3. The Scenario of Internetworking Based on the Three-Sublayer Network-Layer Model

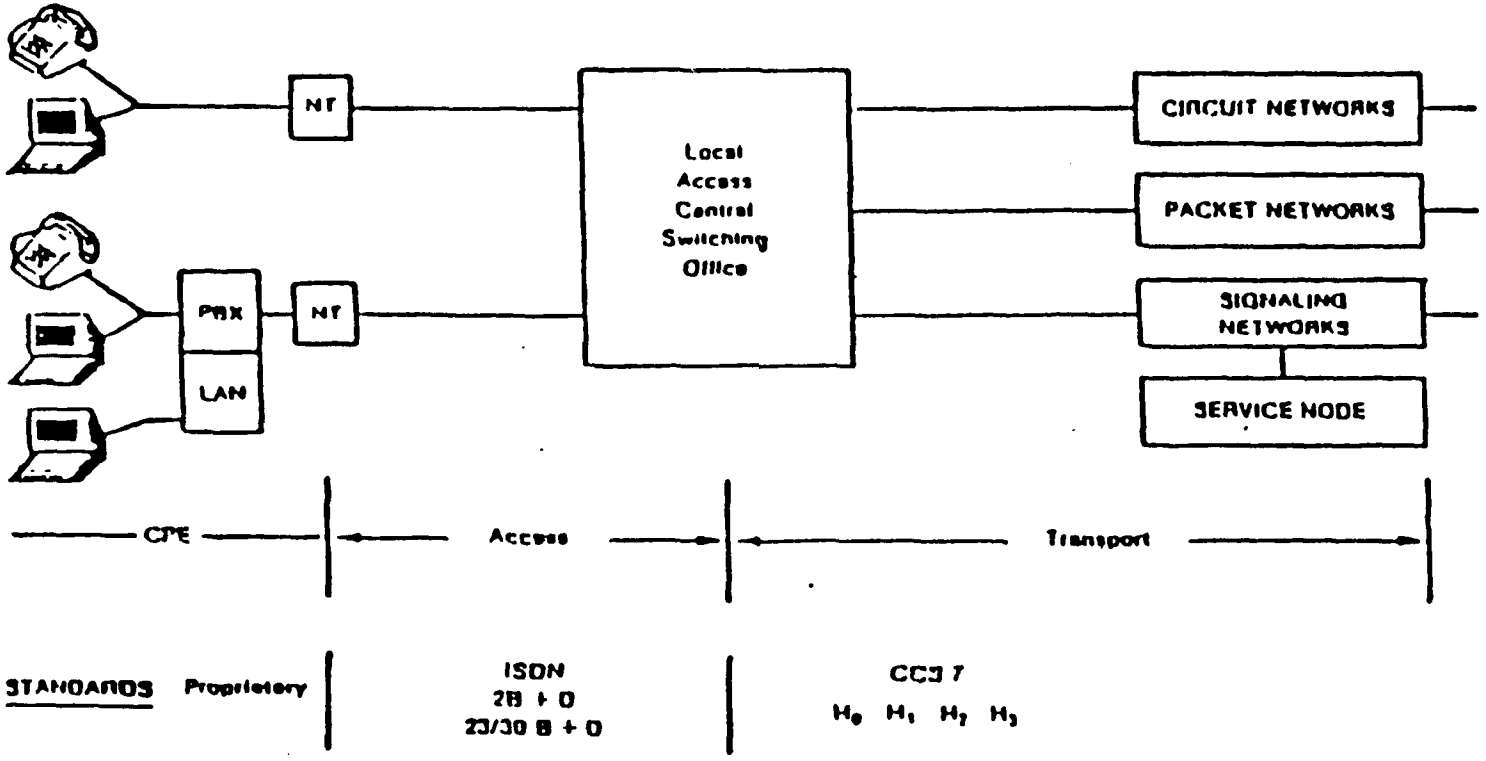
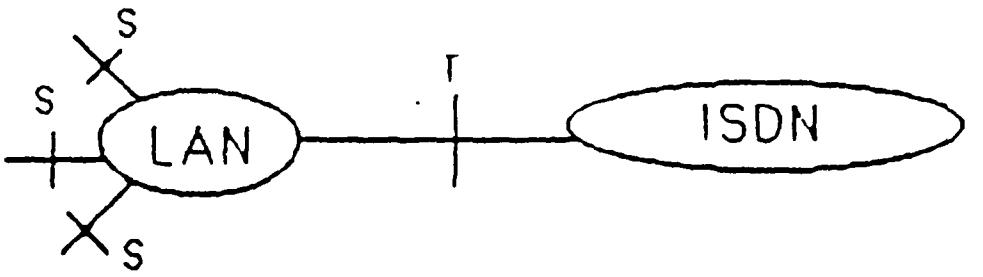


Fig. 3.4. ISDN's Viewpoint of LAN



S,T: ISDN S,T Interfaces.

LAN is connected to the T interface.

S interface is moved to each LAN user.

Fig. 3.5. The Logical Diagram of ISDN's Viewpoint of LAN

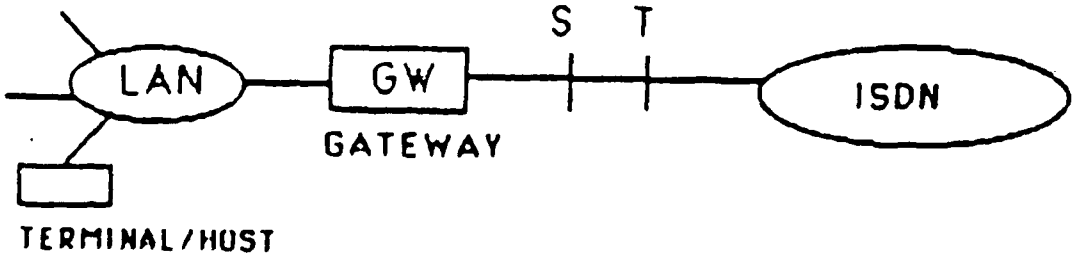
service available to all LAN users. However, providing the "S interface" to LAN users is not a simple task; and no existing LANs can be used without large modifications. Gateways are needed to internetwork the existing LANs with an ISDN.

3.3 ISDN-LAN Gateways

The reasons for connecting LANs to ISDN are:

1. To interconnect LANs that are located at two remote sites;
2. To connect any ISDN terminal to the LANs;
3. To make any ISDN service available to all LAN users.

One approach of the ISDN-LAN internetworking is mentioned in Section 3.2. The other approaches are through ISDN-LAN gateways. Figure 3.6 shows the ISDN-LAN internetworking via gateway. This interconnection is based on the ISO-OSI internetworking model of end-systems and subnetworks mentioned in Section 3.1. Figure 3.7 shows the scenario of interconnecting two remote site LANs via ISDN. Figure 3.8 illustrates the scenario of interconnection between the ISDN end-systems and the LAN end-systems. The issues related to gateway design will be discussed in the following sections.



GW: LAN Gateway is connected to the ISDN S Interface.

Fig. 3.6. The ISDN-LAN Internetworking via a Gateway

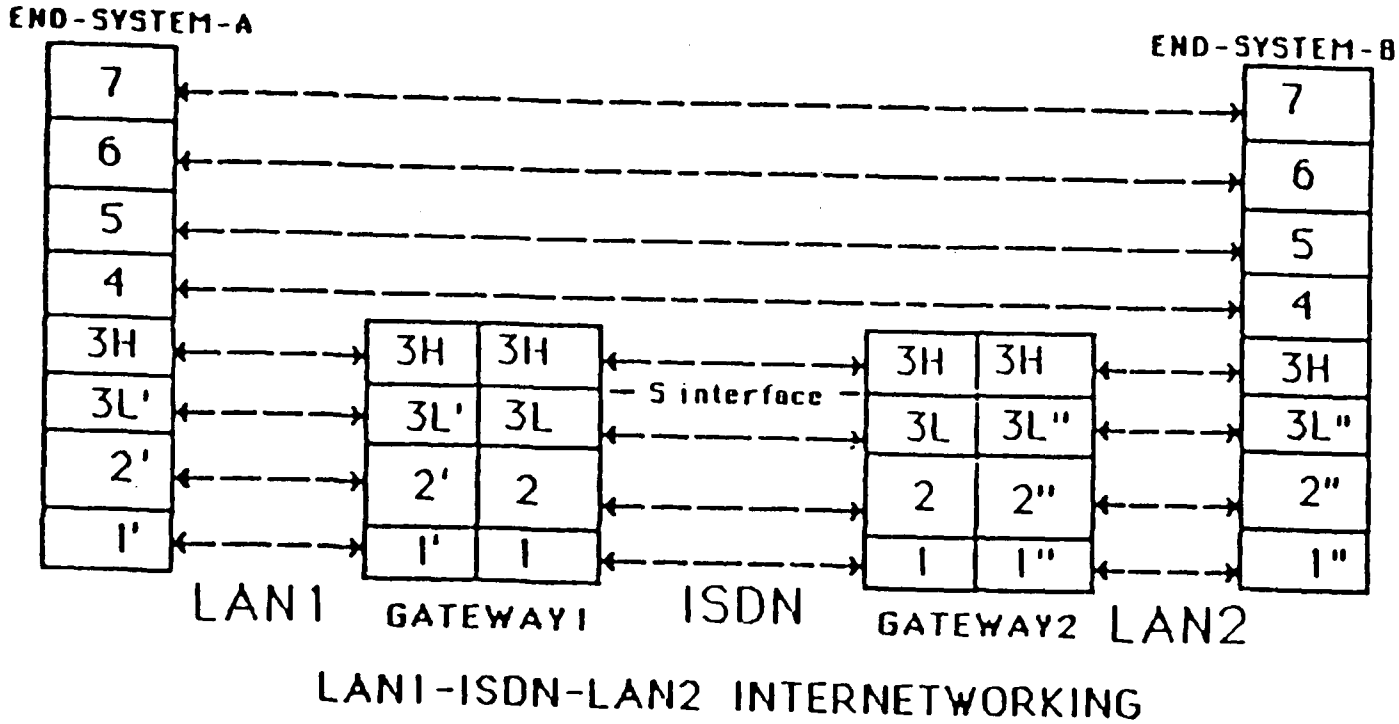


Fig. 3.7. The Scenario of Interconnecting Two Remotely Located LANs via ISDN

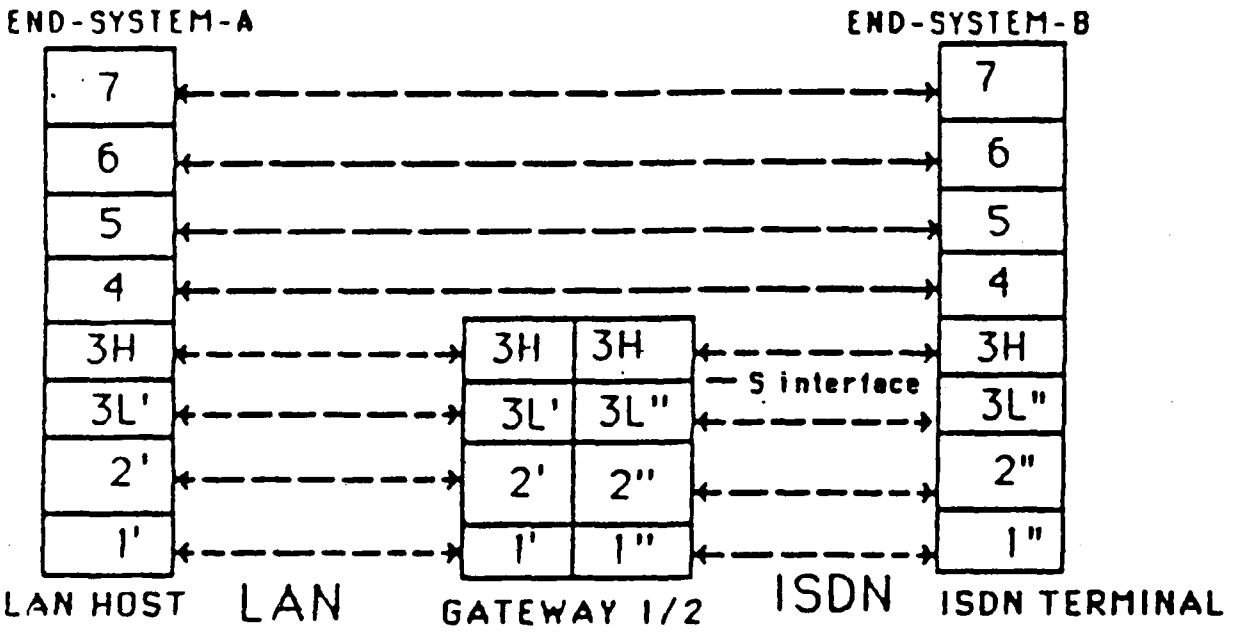


Fig. 3.8. The Scenario of Interconnection Between the ISDN End-Systems and the LAN End-Systems

4. METHODOLOGY FOR COMPUTER NETWORK INTERNETWORKING

4.1 General Considerations

The assumptions of the ISO-OSI Internetworking Model for End-Systems and Subnetworks mentioned in Section 3.1 are not always true for some existing computer networks. For example, the Assumption 1: the communication protocols of End-System A and End-System B are compatible from Layer-4 to Layer-7; however, the layers 4-7 between different networks may not be compatible. The assumption that the Layer-3 Network Layer can be subdivided into sublayers may also be incorrect. To add the Internetwork Sublayers 3H or 3b and 3c into the existing networks requires modification and redesign of hardware and software of the network stations and nodes. Such an approach is usually opposed by network vendors. For the design of future networks, the network compatibility with the ISO and CCITT standards is of highest priority; and the internetworking scenario should fit into the "ISO-OSI Internetworking Model of End-Systems and Subnetworks." However, to handle the internetworking problems of the existing data communication and computer networks, we should consider the more general gateway design approaches.

Figure 4.1 shows the general gateway architecture for internetworking two networks. Figure 4.1 may mislead one to believe that the gateway design must cover all seven layers. Depending on the level of compatibility between the two networks the gateway design can be up to any layer. For example, if the two networks are compatible from layers 3 to 7, then the layer-2 gateway (also called bridge) is possible. If the two networks are

**: Depending on the compatibility of the protocol layers of the two end-systems, the gateway can be up to any layer. For example, the layer-2 gateway is called bridge; the layer-3 gateway is called router.

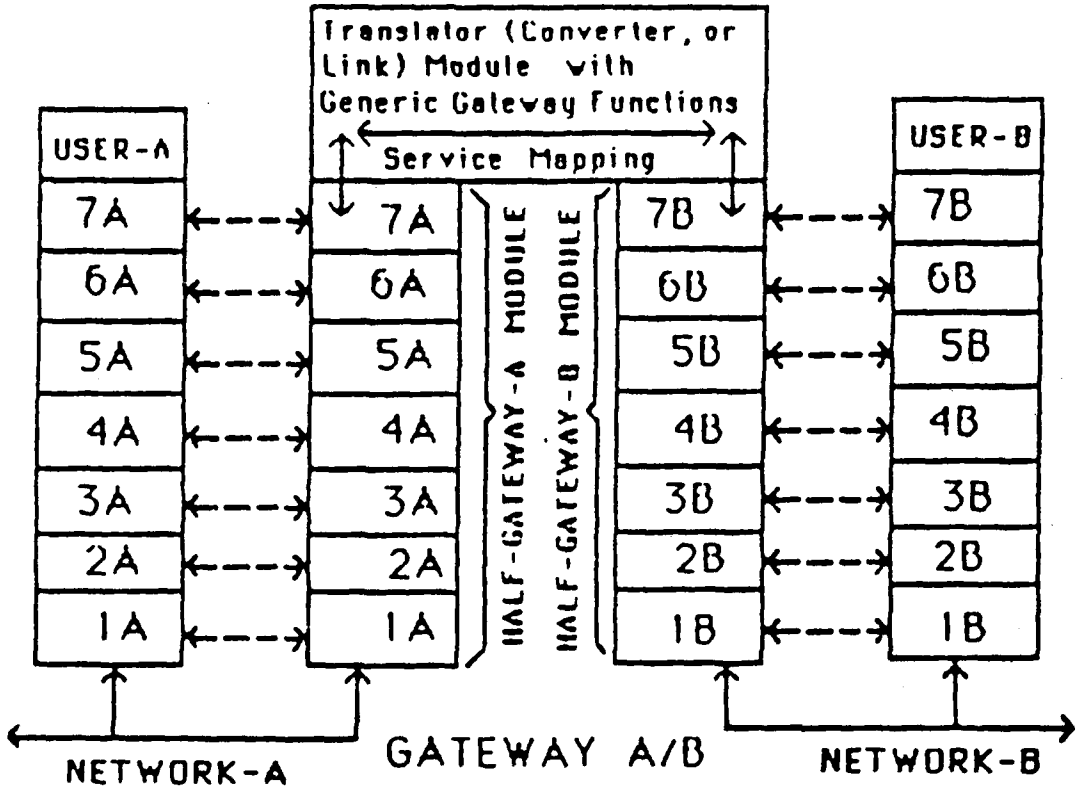


Fig. 4.1. The General Gateway Architecture for Internetworking Two Networks

compatible from layers 4 to 7, then the layer-3 gateway (also called router) is possible.

From Figure 4.1, within the gateway, the layers 1A-7A are the Network-A protocols, and the layers 1B-7B are the Network-B protocols. The required special design part of each specific gateway between two specific networks is the translator (some literatures call it as converter or linker). Although there are some generic functions required for general gateway design, there will be no general gateway which can connect any two different networks; i.e., the gateway connecting two specific networks needs special design considerations which are based on the specific characteristics of the two connected networks. We will discuss the generic gateway functions first then the specific gateway design considerations will be discussed from the viewpoint of practical considerations.

4.2 Generic Gateway Functions

The generic gateway functions are listed as follows:

4.2.1. The hardware and software interface functions and protocols used by networks A and B

These interface functions and protocols let the gateway talk to the two connected networks. Figure 4.2 shows the gateway architecture which decomposes the gateway into two half gateway modules linked by a translator module. Figure 4.1 and Figure 4.2 have the same meaning. The methods of implementing the two half gateway modules and the translator module will be discussed in Section 4.3 -- "Internetworking Approaches: Practical Aspects."

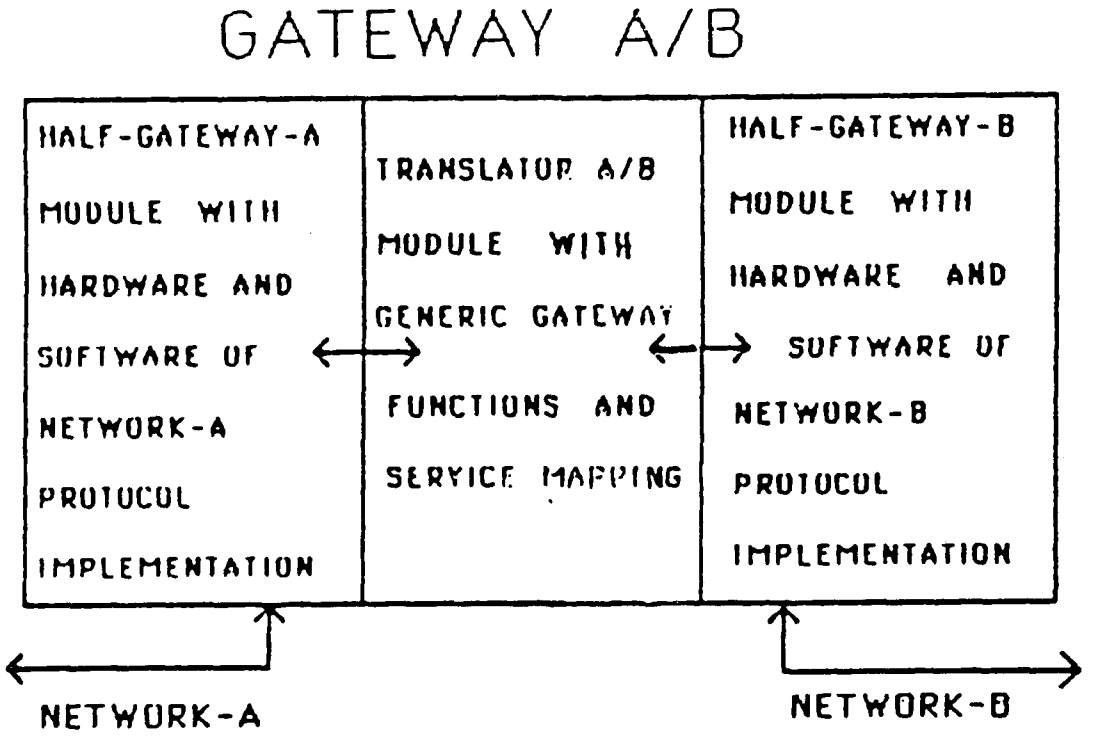
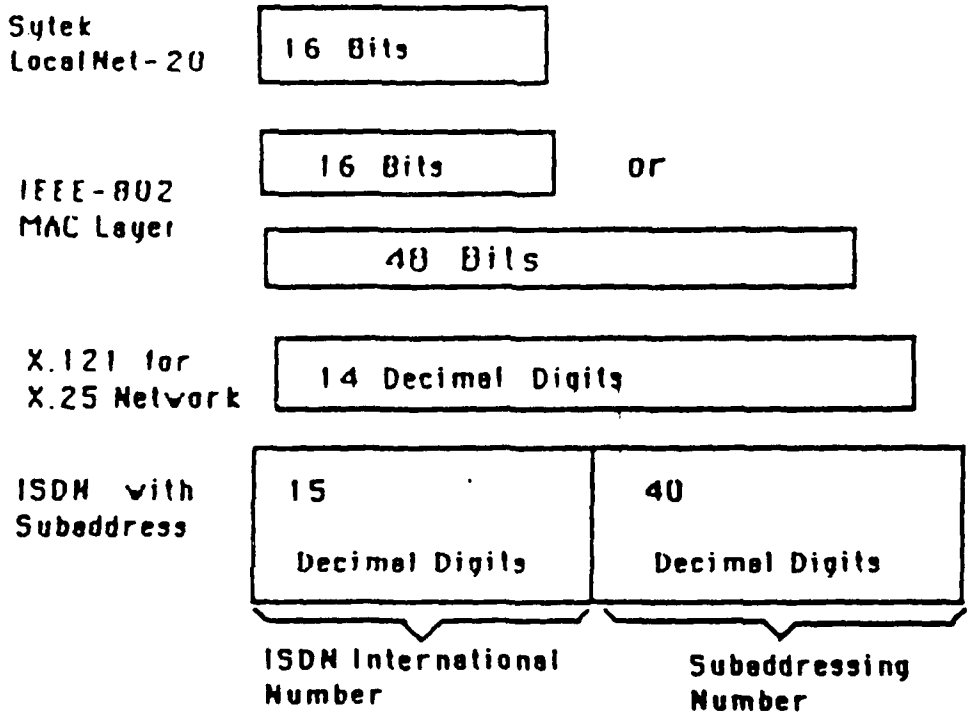


Fig. 4.2. The Gateway Architecture Which Decomposes the Gateway into Two Half-Gateway Modules Linked by a Translator Module

4.2.2. Addressing, Naming, and Routing Functions

A distinction is generally made among addresses, names, and routes. A name specifies what an object is; an address specifies where it is; and a route indicates how to get there. The names, addresses, and routes can be "local" or "global" in the multiple networks internetworking environment. "Local" means intra-network; and "global" means inter-network. To translate "logical name" into "physical address", the name server directory services should be provided. The name server directory services can be centralized or distributed and inside or outside the gateway. A more important function of the gateway is the route selection based on the address generated by the name server.

The addressing spaces or capabilities are different among different networks. Figure 4.3 shows some examples of addressing spaces of different networks. The Sytek LocalNet-20 only has a 16 "binary bit" addressing space. The IEEE-802 MAC layer addressing space can be 16 or 48 binary bits. The X.121 for X.25 network has the addressing space 14 "decimal digits." The ISDN has addressing space 55 "decimal digits". It should be noted that one "decimal digit" is much larger than one "binary bit". So the 55 decimal digit addressing space of ISDN is much larger than the 48 binary bit addressing space of IEEE-802 MAC layer. The 55 digit ISDN addressing space is subdivided into 15 digit basic ISDN address and 40 digit subaddress space. The 15 digit basic ISDN address is used to access the ISDN interface points, e.g., T, S, and R interfaces, within ISDN. The 40 digit subaddress can be used to access the subnetworks outside the ISDN. The mapping and



*: One Decimal Digit is much larger than one Binary Bit.

Fig. 4.3. Some Addressing Spaces of Different Networks

interworking between different addressing spaces of different networks is one important factor of gateway design considerations.

The other gateway function related to addressing, naming, and routing functions is the method used to establish and tear down the end-to-end logical connections in the internetworking environment. One design objective is to make a gateway as user-friendly and transparent as possible. This means that the user interaction when entering addresses should be simple but flexible. When a user wishes to connect his terminal to a remote computer on another network, it is undesirable to have to enter long address strings to make up the call in separate hops, e.g., LAN-WAN-LAN. The ideal solution is to make the user unaware of whether a resource is local or attached to a remote network. This can only be achieved by name server directory services. The user enters a single mnemonic name; and the name server translates the name into a local LAN address, a WAN (Wide-Area-Network) address, and a remote LAN address.

4.2.3 Packet Fragmentation and Reassembly Functions

The maximum allowed packet sizes of interconnected networks are usually different. For packets sent from larger maximum packet size via a gateway to a network with smaller maximum packet size, the gateway should divide the larger packets into smaller packets that can be managed by the second network. The reassembly of these smaller packets can be performed by another gateway or by the receiving end-system.

4.2.4 Buffering Function

The bandwidths (transmission capacities) of networks are different. For example, the bandwidth of Ethernet is 10 Mbits/second; and ISDN provides basic access rate 2B+D (144 Kbps), primary access rate 23B+D (1.5 Mbit/s T1), or future Broadband ISDN rate (135.168) Mbps. To handle the interconnected networks with different bandwidths, the gateway should provide some type of buffering function.

4.2.5 Flow Control Function

Flow control is a procedure through which a pair of communicating entities regulates traffic flowing from source to destination. Such a mechanism is necessary at the gateway in order to protect one network from being overloaded by the other. Dissimilar flow control strategies used in each subnetwork will further complicate the design of the gateway flow control function.

4.2.6 Congestion Control Function

Congestion control is the ability to respond to an overloaded condition within a network or a gateway. It is usually accommodated by detecting a potential overload and cooperating with flow control and routing functions to avoid the overload. If the congestion control is insufficient, some packets are discarded to free the resource. Sometime those discarded packets cause more retransmission from the source; then that makes the congestion condition worse. The discarding packet method is done only as a last resort and shculd be an exception condition in properly designed networks or gateways.

4.2.7 Error Handling Function

When a packet is discarded by gateway for some reasons, e.g., header error or gateway congestion, the gateway should try to inform the packet source station. The gateways should report their operating status among neighboring gateways to provide better routing and error handling functions. Some kind of gateway-to-gateway protocol is required for multiple network internetworking environment.

4.2.8 Access and Security Control Function

Access and security control is needed to permit a gateway to exercise control over the type and rate of traffic entering or leaving networks. The control capability can monitor and bar some specific traffic types. These functions are very important in the gateways for military and banking networks.

4.2.9 Billing and Charging Function

The ISDN or Value-Added Networks (VAN's) charge users, and LANs are usually free to users. The gateway needs mechanisms to record the ISDN or public network billing, and provide the LAN users procedures for verifying the public network billing.

4.2.10 Monitoring and Statistical Functions

The statistical information of traffic through a gateway between specific source and destination networks should be monitored and recorded for future gateway modification and expansion. The number of damaged or discarded packets through gateway should also be recorded for future modifications of gateway flow control, congestion control, and error handling functions. For these reasons, the gateway should have some non-

volatile storage devices to record the statistical data for future investigation.

4.2.11 Protocol Conversion Function

The protocol conversion is the process of mapping of elements of one protocol to another when the two protocols offer "similar services", but are dissimilar in "protocol composition" or "the set of atomic protocol functions." For example, the ISO Transport Layer Protocol Class-4 (ISO TP-4) offers similar functions as the DoD DDN Transmission Control Protocol (TCP) does; however, the protocol compositions of TP-4 and TCP are dissimilar. The Finite State Machine (FSM) concept of protocol is very important in protocol conversion design and implementation. The two famous papers about protocol conversion are:

Green, P.E. Jr., "Protocol Conversion", IEEE Trans. on Comms., Vol. COM-34, No. 3, March 1986.

Groenbaek, I., "Conversion between the TCP and ISO Transport Protocols as a Method of Achieving Interoperability between Data Communications Systems", IEEE J. Select. Areas Commun., Vol. SAC-4, March 1986.

The other research area is the conversion between two protocols offering "dissimilar services." For example, the conversion between the connection-oriented protocol and connectionless protocol. Actually, the ISO OSI Internetworking Model of Sublayers 3a, 3b, 3c, of the Network Layer is also an example of protocol conversion.

4.3 Internetworking Approaches: Practical Aspects

To tackle the internetworking problems, the approaches for future new networks and those for existing networks are different. For the future new networks, if the ISO and CCITT

communication protocol standards are implemented, then the internetworking problems can be minimized. Especially, the ISO-OSI Internetworking Model mentioned in Section 3.1 should be used in End-Systems and all Subnetworks. The three Sublayers 3a, 3b, 3c of Layer-3 Network Layer will make the future gateway design much easier.

However, in the real world there exist a lot of vendor's proprietary networks which were designed and implemented before the complete set of ISO-OSI and CCITT standards were available. The internetworking or gateway design considerations must live with this real-world situation. Therefore the internetworking problems must be approached from hardware, software, and political considerations.

The hardware considerations are:

1. What kind of communication components are available ?
   For example, VLSI chips, communication interface boards, or front-end stand-alone communication boxes.
2. What kind of interfaces or buses are available ?
   For example, Intel Multibus, Motorola VME-bus, DEC Q-bus, RS-422, or RS-232-C interfaces.
3. Where is the gateway implemented ?
   For example, stand-alone chassis, micro-computer, or mini-computer.

The software considerations are:

1. Which layer is the gateway up to ?
   This decision is dependent on the compatibility of layers between the two connected networks.

2. Who provides the software of protocol implementation ?

   Is the third-party software available?

   Do the vendors of the two networks want to provide the proprietary protocol software ?

3. Is the available protocol software portable ?

The available protocol software may run on the operating system which is different from the operating system used by the gateway. Sometimes, transferring the protocol implementation from one operating system to another is very difficult, or even impossible. We published a paper "A Case Study: The TCP/IP/CMOS Kernel Conversion to iRMX Operating System" in the IEEE Phoenix Conference on Computers and Communications, 1988. In that paper, we discussed some issues related to portable communication protocol implementations.

4. Where and how is the translator module implemented ?

In Figure 4.1 and Figure 4.2, the translator module connects the two half-gateway modules. To deal with the existing networks interconnection, the most important thing to be kept in mind is that we cannot ask the network vendors to change their software and hardware of the existing networks. So for the gateway design of existing networks, the implementation of the translator module should be based on the characteristics of the two interconnected networks.

In the following sections, we discuss four approaches for network internetworking. In the discussion of the four approaches, the questions related to the hardware and software considerations of gateway design will be answered. The comparison

of the four approaches is also discussed.

4.3.1 Approach 1: Direct Connection of Network Interface Units

The RS-232-C is the most popular interface port for computers and terminals. For several computer networks, especially LANs, the vendors developed stand-alone, front-end communication boxes with RS-232-C interface. Those communication boxes are also called Network Interface Units (NIUs). The computers and terminals connect the NIUs through RS-232-C interface to form the computer network and to communicate with each other. For example, the LAN vendor Sytek Inc. provides Packet Communication Unit (PCU) boxes for its LocalNet-20 broadband CSMA/CD LAN. The Concord Data Systems (CDS) Inc. provides Token/Net Interface Module (TIM) boxes for its Token/Net broadband Token Passing Bus LAN. To use a modem to access public telephone network, RS-232-C is also a standard interface. Terminal Adapter (TA, see Figure 2.4) with RS-232-C in one end and ISDN S interface in the other end can provide the ISDN access for equipment with an RS-232-C interface.

For those computer networks using stand-alone, front-end Network Interface Units (NIUs) with RS-232-C interface, the simplest internetworking approach is direct connection pairs of NIUs via RS-232 cables. In our Computer Engineering Research Laboratory (CERL), we connect Sytek LocalNet-20 PCU boxes with CDS Token/Net TIM boxes via RS-232-C Null Modem cables. Users in LocalNet-20 LAN can communicate with users in Token/Net LAN via the direct connection of Network Interface Units. Figure 4.4 shows the internetworking scenario of direct connection of NIUs.

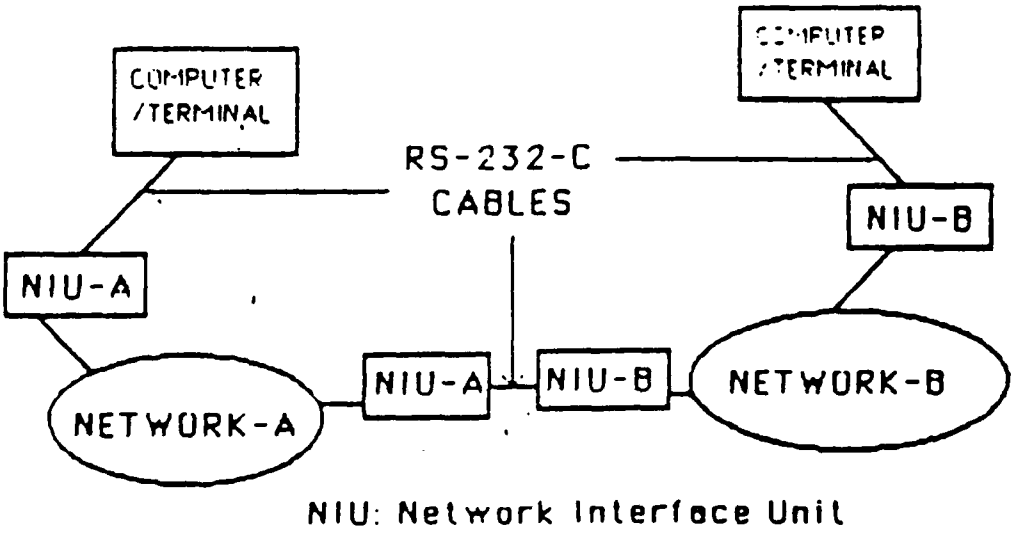


Fig. 4.4. The Internetworking Scenario of Direct Connection of Network Interface Units (NIUs)

By comparing Figure 4.1 with Figure 4.4, we can see that the two half-gateway modules are equivalent to the LocalNet-20 PCU and Token/Net TIM; and the translator module is equivalent to the RS-232-C Null Modem cable. The hardware and software of the two half-gateway modules are inside the PCU and TIM. Because the PCU and TIM are stand-alone, front-end communication boxes, we do not need to worry about where to get the vendors' proprietary software and hardware. This solves the political problem of gateway design regarding vendors' cooperation.

In this internetworking approach, the translator module is the RS-232-C Null Modem cable. The reason to use Null-Modem cable is that both PCU and TIM use the RS-232-C DCE (Data Circuit-Terminating Equipment) interface. How the 25 pins of RS-232-C interface are used is different among vendors. So the RS-232-C interface has earned the distinction of being the most non-standard standard in electronics! Because the use of the RS-232-C 25 pins are different among vendors, the design of the cable to connect two NIUs should follow the pin-assignment of each vendor. The definition of "interface" is "a specification or protocol for how data should be formatted and sequenced to pass between two adjacent devices." From this viewpoint, the cable design for connecting two NIUs is also a type of "protocol conversion."

The internetworking via direct connection of NIUs is simple. However, establishing and tearing-down the end-to-end logical connection must be handled hop-by-hop by the users. The error handling function is also taken care of by the users. In this approach only a few generic gateway functions are provided.

4.3.2 Approach 2: Interconnection through Computer Ports

One objective of gateway design is to make the gateway as user-friendly and transparent as possible. From that point of view, "Approach 1: Internetworking via Direct Connection of NIUs" is not a good approach, although it is the simplest. To make the gateway user-friendly and transparent, the translator module can be implemented in a computer. Figure 4.5 shows the scenario of "Approach 2: Interconnection through Computer Ports." We still use LocalNet-20 and Token/Net internetworking as an example.

From the comparison of Figure 4.1 and Figure 4.5, the two half-gateway modules are still LocalNet-20 PCU and Token/Net TIM. However, the translator module is now inside the computer. So the generic gateway functions mentioned in Section 4.2 such as: naming, addressing, and routing functions; packet fragmentation and reassembly functions; buffering function; flow control function; congestion control function; error handling function; access and security control functions; billing and charging function; monitoring and statistical functions; and protocol conversion function; can be implemented in the translator module inside the computer.

Actually, "Approach 2: Interconnection through Computer Ports" can handle another kind of situation. Some network vendors provide communication adapter boards to insert into the computer bus. For example, the Sytek Inc. provides a broadband CSMA/CD communication adapter board to insert into the IBM-PC or IBM-PC compatibles computer bus to form a PC-Net broadband CSMA/CD LAN. The Intel Corp. provides several communication boards to insert

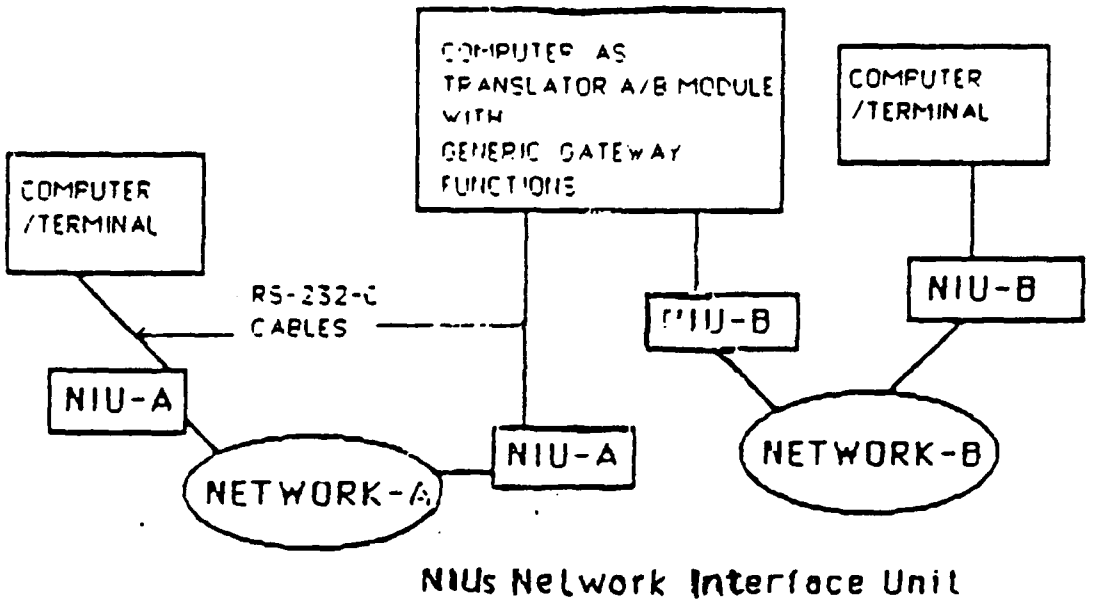
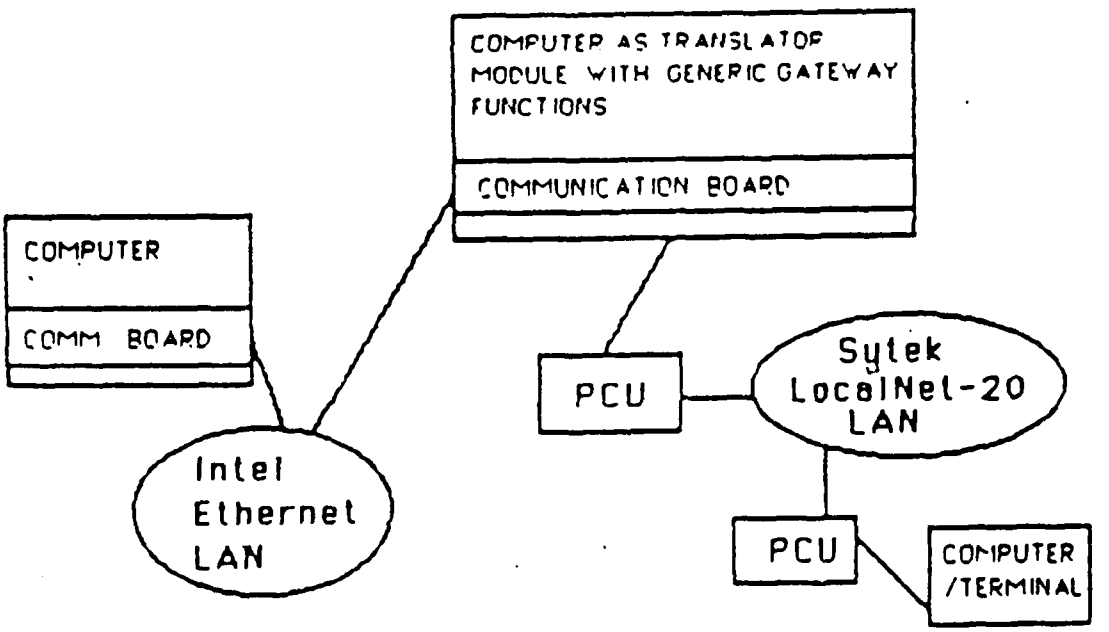


Fig. 4.5. The Scenario of Internetworking Through Computer Ports

into the Intel computer Multibus to form an Ethernet LAN. Figure 4.6 shows the scenario of internetworking the Intel Ethernet LAN with Sytek LocalNet-20 LAN. The Intel Ethernet communication board is inserted into the Intel 310 computer Multibus as the Ethernet side half-gateway module; and the Sytek PCU box is connected to the RS-232-C port of Intel 310 computer as the LocalNet-20 side half-gateway module. The translator module connecting the two half-gateway modules is implemented inside the Intel 310 computer.

In this "Approach 2: Internetworking through Computer Ports", the two half-gateway modules are based on front-end communication boxes or communication adapter boards provided by network vendors. The translator module, which is implemented inside the computer for Approach 2, can provide the generic gateway functions mentioned in Section 4.2. The big drawback of Approach-2 is the speed limitation of RS-232-C interface ports and the stand-alone, front-end communication boxes usually supporting few users in one box. However, if only a few users occasionally use internetwork traffic, the internetworking through computer ports works well and satisfactorily.

The big advantage of Approach 2 is that generic gateway functions in the translator module can be developed and tested more easily in this internetworking through computer ports approach. If more internetwork traffic is required, the "Approach 3: Integrated Gateway" is needed. However, the developed and tested generic gateway functions in the translator module from Approach 2 can be used in Approach 3 with some modifications.



PCU: Sytek Packet Communication Unit.
Comm. Board: Intel Ethernet Communication Board.

Fig. 4.6. The Scenario of Internetworking the Intel Ethernet LAN with the Sytek LocalNet-20 LAN

4.3.3 Approach 3: Integrated Gateway

To support bigger bandwidth and multiple user sessions for internetworking, Approach 3: Integrated Gateway, which is more complicated than Approach 1 and Approach 2, should be taken. The architecture of "Approach 3: Integrated Gateway" is the same as Figure 4.1. The big difference between Approach 2 and Approach 3 is that the two half-gateway modules of Approach 3 are based on the network vendors' proprietary internal design information of hardware and software implementations. In Approach 1 and Approach 2, we use the stand-alone, front-end communication boxes (NIUs) or communication adapter boards as the two half-gateway modules; so the required information and cooperation from network vendors is minimum. However, the "Approach 3: Integrated Gateway" needs the network vendors' cooperation in providing the hardware and software internal design and implementation information of the two interconnected networks. To obtain the internal design and implementation information from network vendors is the biggest challenge in this integrated gateway approach.

The integrated gateway is a multi-processor system which consists of several single board computers (SBC's). These SBC's are inserted into a stand-alone chassis, or micro-computer bus, or mini-computer bus. The computer interface bus may be: Intel Multibus, Motorola VME-bus, DEC Q-bus, IBM-PC bus, etc. Basically, all of the hardware and software design principles of multi-processor systems can be applied to the integrated gateway design. Each of the two half-gateway modules and translator module can be implemented in one or more SBCs. Figure 4.7 shows

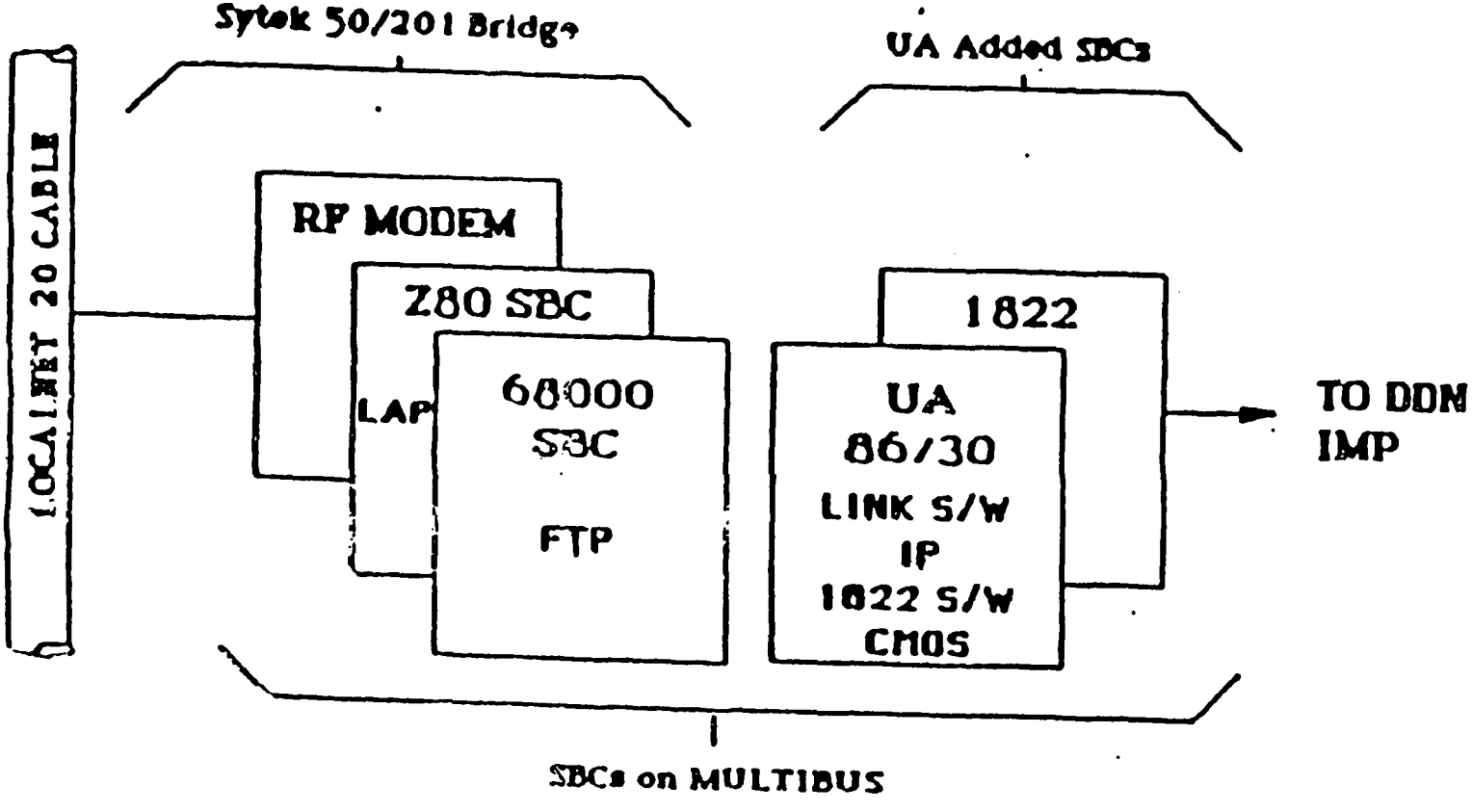


Fig. 4.7. One Example of Integrated Gateway Internetworking the Sytek LocalNet-20 LAN with DoD Defense Data Network

one example of integrated gateway which interconnects Sytek LocalNet-20 LAN and DoD Defense Data Network (DDN). This integrated gateway was developed by our CERL gateway research team. We describe the integrated gateway design steps as follows:

4.3.3.1 Step 1: Understand and Use Each of the Two Networks

The gateway designer should understand the hardware, software, and protocols of each of the two interconnected networks, especially, in the case of vendors using proprietary non-standard protocols. If possible, the designer should also use each of the two networks to understand the user-network interface, the network access procedure, the session establishing and terminating procedures, the error handling procedure, and the characteristics of each network. In the case of internetworking the existing network with the future new network, e.g., LAN-ISDN Internetworking, an understanding of the protocols and characteristics of the future new network is very important.

4.3.3.2 Step 2: Start Internetworking from Approach 1 and Approach 2

The philosophy of gateway design, implementation, and testing is that the internetworking approaches start from simple to complex. If the RS-232-C interface Network Interface Units (NIUs) are available, "Approach 1: Direct Connection of NIUs" is simple and easy. Approach 1 can give the gateway designer some experiences such as: how the end-to-end logical connection is established and torn down, how the error conditions are handled, etc. Such experiences are important in the future approaches of designing the user-friendly, transparent translator module which connects the two half-gateway modules.

Based on the computer and available NIUs, the "Approach 2: Interconnection through Computer Ports" can develop and test the important gateway translator module in which the generic gateway functions are implemented. The gateway translator module with generic gateway functions developed in Approach 2 can be used in the "Approach 3: Integrated Gateway" with some modifications.

4.3.3.3 Step 3: Decide Which Layer Gateway Is Required

The criteria to choose the layers for a gateway are:

1. Based on Figure 4.1 and depending on the compatibility of the protocol layers of the two end-systems, the layer up to which the gateway to be built is chosen. For example, if the two end-systems are compatible from Layer-(N+1) to Layer-7, then a Layer-N gateway can be built. This scenario is shown in Figure 4.8.

2. From the point of view of efficiency, the lower layer the gateway is, the more efficient it is. More layers in the gateway will take more processing time. If the internetwork traffic flow is very large, the processing burden in the gateway will be too heavy to be handled. Some kind of high-speed parallel-processing architecture for the gateway is required. Actually, the gateway architecture, which consists of translator and half-gateway modules, is suitable for a multi-processor, parallel-processing implementation.

3. From a practical viewpoint, how low the gateway layer being chosen is also dependent on two factors:

(i) The Criterion 1 (see Figure 4.8) above should be obeyed.

(ii) The network vendors' willingness to provide the proprietary hardware, software, and internal design information

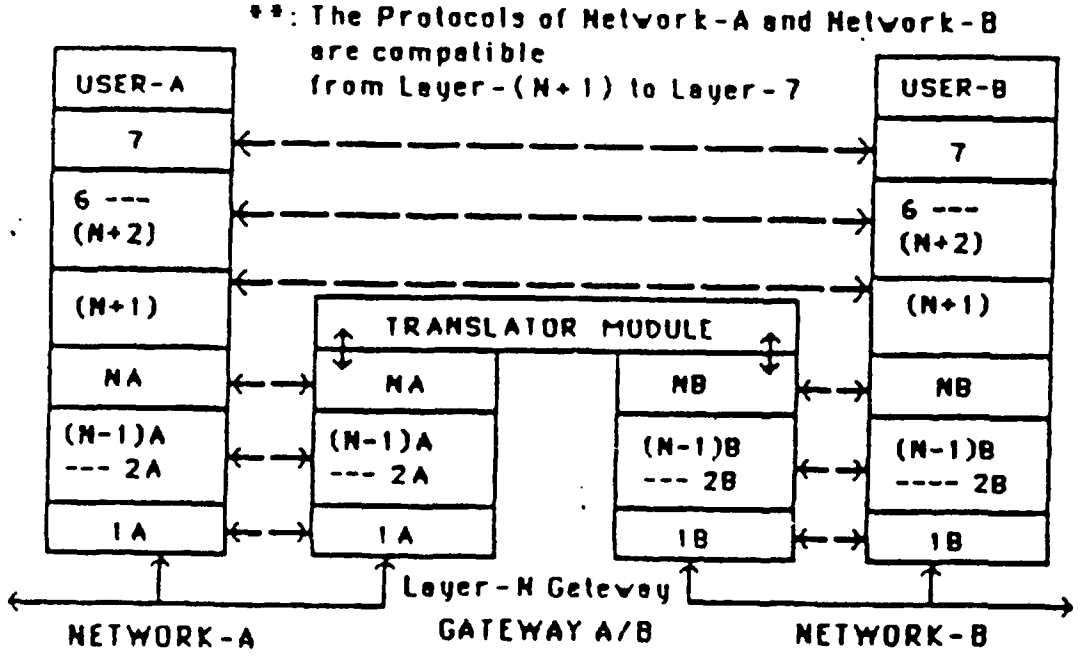


Fig. 4.8. The Scenario of Choosing the Gateway Layer

becomes the most important factor in Integrated Gateway design. For example, the end-systems are compatible from Layer-(N+1) to Layer-7, i.e., a Layer-N gateway is possible; however, the available hardware, software, and internal design information from network vendors are in the Layer-M, where M is greater than N. In such case, the real Integrated-Gateway will be a Layer-M gateway.

4.3.3.4 Step 4: Obtain the Required Information from Network Vendors

Based on Steps 1, 2, and 3, the gateway designer lists all the needed hardware, software, interface, and internal design information which the two network vendors should provide. A lot of political considerations are involved in this Step 4. Under what conditions the network vendors agree to provide the needed information, e.g., non-disclosure agreement, license fee, etc. What kind hardware interface, e.g., Intel Multibus, Motorola VME-bus, DEC Q-bus, IBM-PC bus, or some special buses, that vendors' hardware can be inserted ? What kind of operating system can the vendors' protocol implementation run ? Is there any interface conflict between the software and hardware products from the two network vendors ? Many such questions should be answered before the Integrated Gateway design decision is made.

4.3.3.5 Step 5: Decide What Kind of Chassis or Computer to Build the Gateway

The Integrated Gateway is a multi-processor system which comprises several Single Board Computers (SBCs). So the Integrated Gateway should be in a stand-alone chassis with interface bus or in a micro-computer or mini-computer with enough

interface slots on the backplane.

If the stand-alone chassis is chosen, then the software will be in Read Only Memory (ROM) on SBCs; or the software is developed on a host computer, then it is downloaded to the target SBCs. Using the stand-alone chassis, the software development and testing are on separate systems, i.e., developed on a host computer and tested on SBCs. Such separation of development and testing is not convenient. The name server, and monitoring and statistical functions of generic gateway functions require some kind of non-volatile storage devices such as floppy or hard disk drives; however, the stand-alone chassis usually does not provide non-volatile storage devices. For the two reasons above, a micro-computer or a mini-computer with enough interface slots is the preferable candidate for Integrated Gateway.

4.3.3.6 Step 6: Design the Translator Module to Interface with the Two Half-Gateway Modules

We mentioned that the procurement of the network internal design information, hardware, and software, i.e., the vendors' proprietary protocol implementation, from the network vendors is the biggest challenge in this Integrated Gateway approach. Now we assume that we can get the necessary cooperation and support from network vendors, i.e., the network vendors can provide the hardware and software of the two half-gateway modules for the Integrated Gateway approach. Then the next challenge is how to implement the translator module, which provides most of the generic gateway functions, to interface and connect the two half-gateway modules.

Because every network has its own specific characteristics,

the design and implementation of each translator module will be different among all integrated gateway cases. That is, although the general principles are the same, the design and implementation of each translator module should reflect the special characteristics of the two interconnected networks. Because the translator module in Approach 2 can be used in Approach 3 with some modifications, and Approach 2 is much easier in implementation and testing, we suggest that "Approach 2: Internetworking through Computer Ports" should be taken before "Approach 3: Integrated Gateway."

4.3.3.7 Step 7: Implementation and Testing of Integrated Gateway

The integrated gateway is a complicated multi-processor, parallel-processing system with hardware and software provided by the two network vendors and the gateway designer. The implementation and testing of the Integrated Gateway is a tremendous task. All the design, implementation, and testing principles of the multi-processor, parallel-processing systems can be applied to the integrated gateway. The philosophy here is that during the designing process, a method to test the gateway should always be kept in mind; and the implementation and testing should start from basic to advanced, from simple to complex.

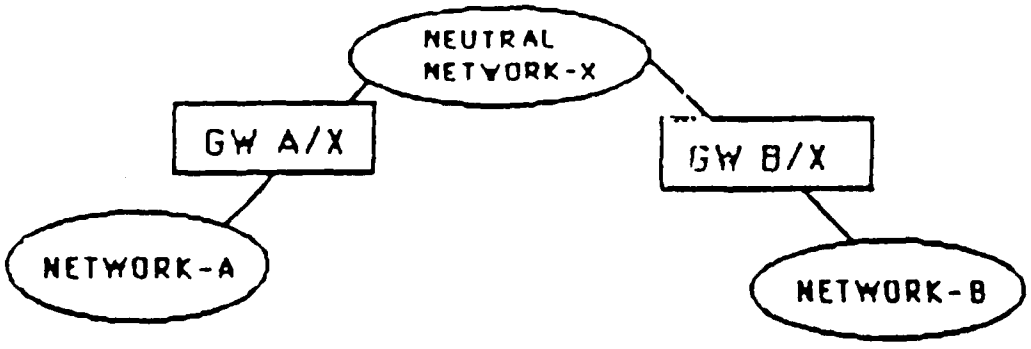
For example, we cannot put all the generic gateway functions mentioned in Section 4.2 into the integrated gateway in the beginning. These generic gateway functions should be added into the Integrated Gateway one by one, and tested one by one in sequence. The first step of implementation is the simplest translator module without any complex generic gateway function.

The simplest translator module is not user-friendly or transparent, it just interfaces and connects the two half-gateway modules provided by the two network vendors. The purpose of this first step is to make sure that the two half-gateway modules can interwork together and can provide the internetworking end-to-end connection via this simple gateway.

After the first step implementation and testing is passed, then the generic gateway functions such as: protocol conversion function; addressing, naming, and routing functions; packet fragmentation and reassembly functions; buffering function; flow control function; congestion control function; error handling function; access and security control functions; billing and charging functions; and monitoring and statistical functions can be added into the translator module. The implementing and testing these generic gateway functions should be one by one in sequence. We emphasize here again that although the general principles of these generic gateway functions are the same, the implementation of them will be different among different integrated gateways which connect pairs of different networks. That is, N(N-1)/2 different integrated gateways are needed for N different networks.

4.3.4 Approach 4: Gateway Design via a Neutral Network

Figure 4.9 shows the scenario of internetworking via a neutral network. Figure 4.10 shows the architecture of Gateway Design via a Neutral Network. The gateway architecture of this Approach 4 is the same as that of Figure 4.1. The design, implementation, and testing procedures of this Approach 4 gateway



The Neutral Network-X should be a well-known standard network.

The Neutral Network-X can be: ISO-OSI Network,
DoD DDN Network,
X.25 Network, or
ISDN Network.

Fig. 4.9. The Scenario of Internetworking via a Neutral Network

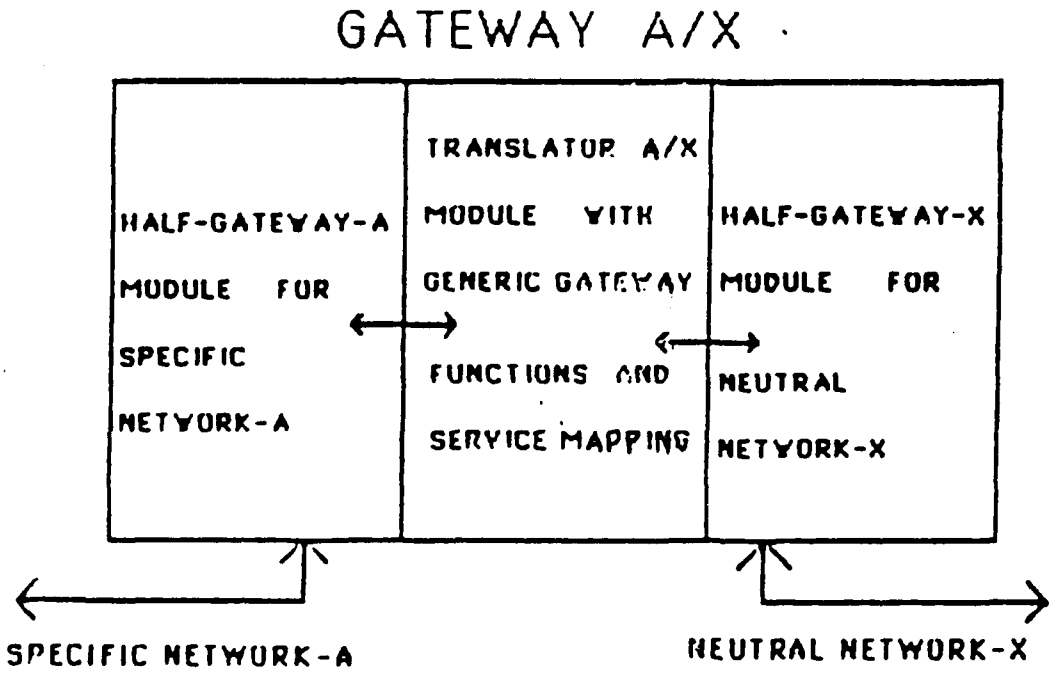


Fig. 4.10. The Architecture of Gateway Design via a Neutral Network

are the same as in Approach 3: Integrated Gateway. However, the difference in this Approach 4 gateway is that one half-gateway module is implemented with well-known standard protocols such as: ISO-OSI protocols, DoD DDN (Defense Data Network) protocols, CCITT X.25 protocols, or CCITT ISDN protocols. That is, the Neutral Network can be ISO-OSI network, DoD DDN network, X.25 network, or ISDN network. This "Approach 4: Gateway Design via a Neutral Network" has some advantages and disadvantages. We discuss them as follows:

The advantages of "Gateway Design via a Neutral Network" are:

1. In Approach 3: Integrated Gateway, N(N-1)/2 integrated gateways are needed for N networks. In Approach 4: Gateway Design via a Neutral Network, because any two networks can be interconnected via the Neutral Network, there need only be N gateways for N networks.

2. Because the chosen Neutral Network is a well-known standard network such as X.25 network or ISDN, the protocol implementation of the half-gateway module connecting the Neutral Network is easier to implement it or to obtain it from third-party organization.

3. We mentioned that the biggest challenge in Approach 3: Integrated Gateway is the procurement of the necessary internal design information of vendors' proprietary protocol implementations from the two network vendors. In Approach 3, we must handle such political considerations with two network vendors. In Approach 4: Gateway Design via a Neutral Network, we only require to handle such political considerations with one

network vendor, because of the Advantage 2 mentioned above.

4. If the gateway is designed by network vendor himself, then the Approach 4: Gateway Design via a Neutral Network will be no political considerations involved at all. For the half-gateway module connecting the vendor's proprietary network, the vendor has all the necessary internal design information. For the half-gateway module connecting the Neutral Network, because the Neutral Network is a well-known standard network, to obtain or to implement the hardware and software of standard protocols is easier. For this reason, the network vendors favor this "Approach 4: Gateway Design via a Neutral Network."

The only disadvantage of this "Approach 4: Gateway Design via a Neutral Network" is the possible overhead and loss of efficiency. We will consider two situations: Case 1: Connecting two remotely located LANs via a Neutral Network; Case 2: Connecting two LANs located at the same site via a Neutral Network. For Case 1, the scenario in Figure 4.9 is essential and justified, there are no overhead and no loss of efficiency. For Case 2, because the two LANs are located at the same site, to connect them via the Neutral Network means the Neutral Network will be overhead. The packets from one LAN to the other LAN at the same site still go through the extra Neutral Network. The extra protocol processing delay in the extra Neutral Network causes the loss of efficiency in Case 2.

4.4 Summary and Comparison of these Four Approaches

We have mentioned the advantages and disadvantages in the discussion of each approach. The summary and comparison here will be based on practical aspects, that is, based on: What is the internetwork traffic? What kind of services does the user want? What kind of services can be provided by each approach? How much time is required and what is the cost in each approach? From overall considerations, which is the most cost-effective internetworking approach to satisfy the user's need within time and cost limits? Actually, the four approaches are related, i.e., the experiences gained from one approach will help the other approach. Sometimes it is hard to decide which internetworking approach is the best one to satisfy the user. The advantages and disadvantages of each internetworking approach are summarized as follows:

Approach 1: Direct Connection of Network Interface Units

Advantages:
1. The simplest internetworking approach, usually only RS-232-C cables are required.
2. Developing time and cost are minimum.
3. Use stand-alone front-end Network Interface Units, the required network vendors' support is minimum.
4. Suitable for small internetwork traffic.

Disadvantages:
1. Not user-friendly, not transparent.
2. Limited internetworking bandwidth and speed.

Approach 2: Internetworking through Computer Ports

Advantages: 1. The computer can be used as the translator module to implement the generic gateway functions to provide user-friendly, transparent services.

2. Use the stand-alone, front-end NIUs or communication adapter boards, only little network vendors' support is required.

3. suitable for small internetwork traffic.

4. The translator module with generic gateway functions can be used in Approach 3.

Disadvantages: 1. Limited internetworking bandwidth and speed.

Approach 3: Integrated Gateway

Advantages: 1. A multi-processor, parallel-processing system can satisfy the high volume internetworking traffic.

2. If end-systems are compatible from Layer-(N+1) to Layer-7, then an optimized Layer-N gateway can be built. The lower layer the gateway is, the more efficient it is.

3. The high-performance generic gateway functions can be provided.

Disadvantages: 1. The proprietary, internal design information provided by network vendors is required.

2. The development cost and time are maximum.

Approach 4: Gateway Design via a Neutral Network

Advantages:

1. It is an integrated gateway, however, one half-gateway module connects a well-known standard network. The half-gateway module for standard network is easier to implement.
2. Two remotely located LANs can be interconnected via the Neutral Network.
3. If the gateway is designed by the network vendor, he has all the proprietary internal design information of one half-gateway module, and the other half-gateway module is based on well-known standard protocols. So the network vendors favor Approach 4: Gateway Design via a Neutral Network.

Disadvantages:

1. If the two LANs are located at the same site, then the extra Neutral Network becomes an overhead. It will cause extra protocol processing delay and loss of efficiency.

Choosing the most cost-effective internetworking approach should base on several factors: such as services wanted by users, internetworking traffic, cost and time limitations, required support and cooperation from network vendors, etc. We suggest four internetworking approaches which include the simplest "Approach 1: Direct Connection of NIUs" and the complicated multi-processor, parallel-processing gateway design in "Approach 3: Integrated Gateway." The "Approach 4: Gateway Design via a Neutral Network" will become more important when the ISO-OSI standard network and CCITT ISDN network become mature and popular

in the future. We emphasize here again that the internetworking design, implementation, and testing should start from basic to advanced, from simple to complex. Although the implementation of each specific gateway, which interconnects two specific networks, is different from one another, the general internetworking principles are the same.

We have described the general internetworking principles in this chapter. We will discuss the "ISDN -- LAN (TOP or MAP) Gateway" in Chapter 5, and the "ISDN/DDN Gateway" in Chapter 6.

5. ISDN-LAN GATEWAY DESIGN

5.1. General Considerations

This ISDN-LAN gateway design will follow the general principles, guidelines, and methodology of internetworking approaches which were described in Chapter 2, Chapter 3, and Chapter 4. Before we go into the details of this specific ISDN-LAN gateway design, we briefly review the general internetworking approaches in Chapter 4.

In Chapter 4, we described the general gateway model (see Fig. 4.1 and Fig. 4.2). The generic gateway functions were discussed in Section 4.2. We also proposed four internetworking approaches in Section 4.3. Based on some practical aspects and constraints, those four internetworking approaches were compared in Section 4.4. The final goal of internetworking two different networks is Approach-3: Integrated Gateway. The general procedures of integrated gateway designs and implementations were described in Section 4.3.3. Those general procedures are outlined again as follows:

1. Understand and Use Each of the Two Networks (A&B).
2. Start Internetworking from Approach-1 and Approach-2.
3. Decide Which Layer Gateway Is Required.
4. Obtain the Required Information from Network Vendors.
5. Decide What Kind of Chassis or Computer to use for implementing the Gateway.
6. Design the Translator Module to Interface with the Two Half-Gateway Modules.
7. Implement and Test the Integrated Gateway.

The originality of internetworking problems comes from the incompatibility of the two interconnected networks. Figure 5.1 shows the relationships between the OSI Reference Model (Architecture), OSI Service Definitions, OSI Protocol Specifications, and Implementations. Usually, most people assume that the incompatibility comes from the two interconnected networks using different sets of protocols. However, two networks using the same set of protocols may still be incompatible. The problem is that there are different parameters and options to be used by the protocol implementor even when using the same set of protocols. One example of this type of incompatibility problem is the implementations of CCITT X.25 protocol. X.25 covers the lower three layers of the OSI Seven Layer Reference Model. Figure 5.2 shows the three X.25 packet switched public data networks implemented by Transpac in France, PSS in United Kingdom, and DXX in Japan. It can be seen that the X.25 parameters and options used by those three X.25 networks were different (based on 1983 information) [24]. These three X.25 networks were incompatible, even though they used X.25 standard protocol.

From the examples of X.25 networks, we emphasize again that the gateway designer must study and understand the detailed implementations, e.g., parameters and options, of the two interconnected networks. That is, the real design and implementation of a gateway to internetwork two networks should be based on the detailed implementation and characteristics of the two interconnected networks.

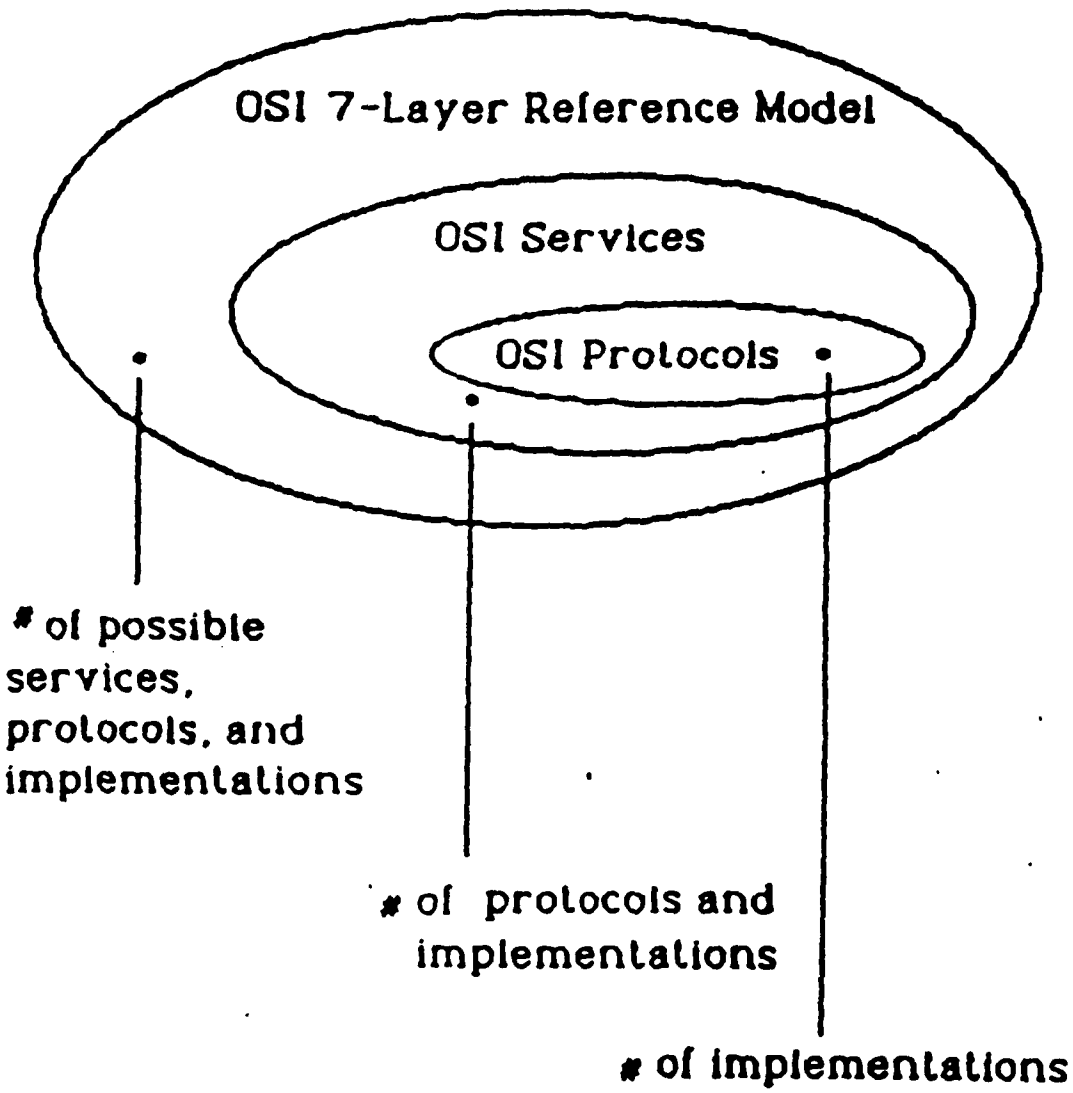


Fig. 5.1. The Relationships between the OSI Reference Model, OSI Service Definitions, OSI Protocol Specifications, and Implementations

HISTORY OF CCITT X.25

CCITT PLENARY ASSEMBLY (P.A.):

VIth P.A. 1976, Orange Book

VIIth P.A. 1980, Yellow Book

VIIIth P.A. 1984, Red Book (ISDN)

ISDN: Integrated Services Digital Network

X.25 (1976), X.25 (1980), X.25 (1984)

Comparison of Differences in X.25 Public Networks

Country Network	France Transpac	U.K. PSS	Japan DXX
PACKET LEVEL:			
SEQUENCE NUMBERING	8 (BASIC)	8 (BASIC)	128 (EXTENDED)
PACKET SIZE	32, 128	128, 256	128, 256
MAX WINDOW	3	7	15
REVERSE CHARGING	YES	NO	YES
LINK LEVEL:			
MAX. FRAME SIZE	128	256	1024
RETRANSMISSION TIMEOUT-T1 (SEC)	0.4 -- 1.5	10	2--8
MAX NUMBER OF RETRANSMISSION TRIES	10	20	25

*** 1983 INFORMATION

Fig. 5.2. The Three X.25 Packet Switched Public Data Networks

5.2 Implementation Plan of ISDN for the U.S. Army

The following information was obtained from the paper published in the IEEE Communications Magazine, December 1987,

"Army Implementation of ISDN,"

by Joseph J. Rudigier, Chief of the Systems and Technology Division of the Plans Directorate of the U.S. Army Information Systems Command at Fort Huachuca, Arizona [25].

Figure 5.3 shows the Department of Defense (DoD) ISDN organization. Figure 5.4 shows the DoD Defense Communications Agency (DCA) proposed mid-term ISDN CONUS architecture. Figure 5.5 shows the DCA proposed far-term ISDN architecture. The plans call for a mid-term ISDN Architecture that is based on the 1988 CCITT standards. Long-haul ISDN services in the CONtinental United States (CONUS) will be obtained by DCA under a service contract arrangement.

In the DCA proposed mid-term ISDN CONUS architecture, LAN's do not interconnect the commercial ISDN switching node directly. Instead, LAN's interconnect with ISDN PABX's, then the PABX's access the commercial ISDN switching node. Thus our ISDN-LAN gateway design will be based on internetworking a LAN and an ISDN-compatible PBX.

In the DCA proposed far-term ISDN architecture, the plans for the 2005 time-frame call for the DoD ISDN switching and network control to be fully integrated. The LAN's interconnect with the WideBand (WB, Fiber Optic Cable) ISDN Network Termination (NT) to access ISDN. Considering the high speed of many LAN's (Mbits/sec), this kind of wideband fiber optic cable interface to

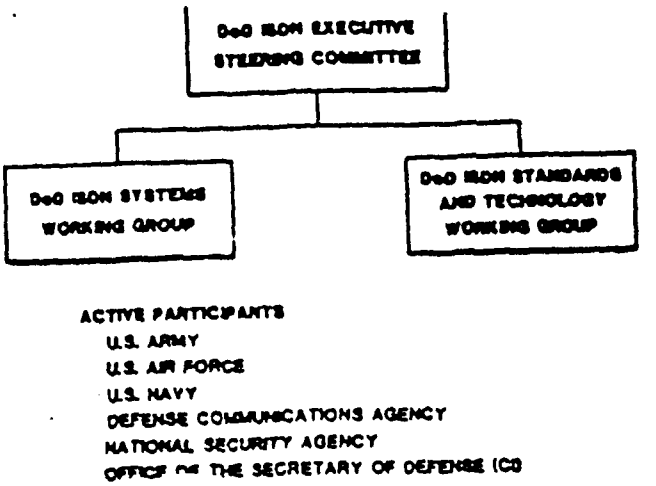


Fig. 5.3. The DoD ISDN Organization

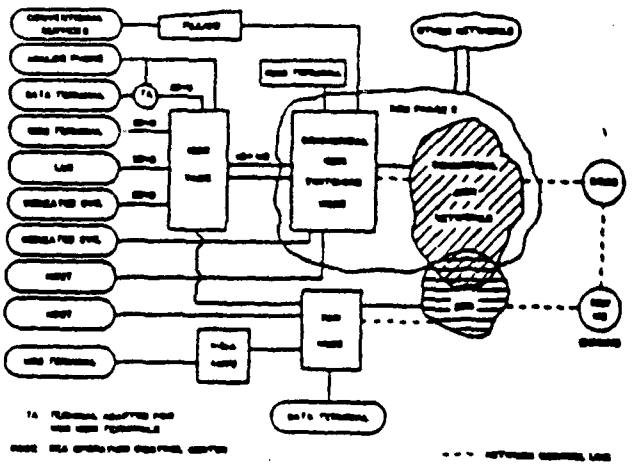


Fig. 5.4. The DoD DCA Proposed Mid-Term ISDN CONUS Architecture

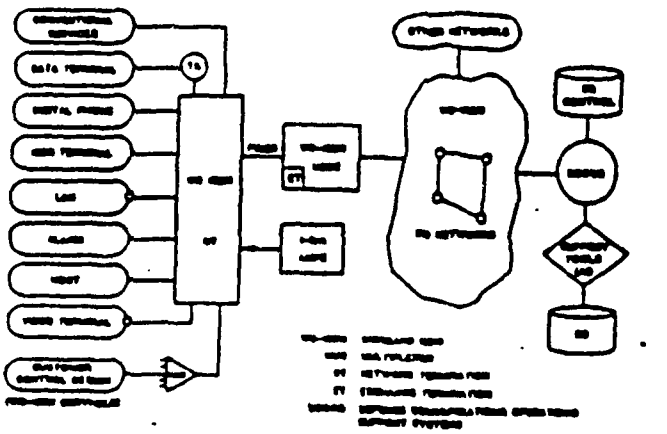


Fig. 5.5. The DoD DCA Proposed Far-Term ISDN Architecture

wideband ISDN is more suitable for ISDN-LAN gateway design. However, since the time-frame of wideband ISDN is after the year 2000 [26], we leave the fiber optic cable ISDN-LAN Gateway Design for future study.

The following paragraph is directly quoted from Ref [25]: "While planning continues for the transition to ISDN, local area networks (LANs) are being installed at many Army installations. The Army policy is to use LANs that meet the IEEE 802.3 standard. Generally it has been assumed that LANs will interface with ISDN through terminal adapters (TAs) or gateways. However, new LAN standards and technologies are becoming available, including Fiber Data Distribution Interface (FDDI) which can operate at rates up to 200Mb/s. Also, office automation needs are continuing to expand, both in numbers and required bandwidth. As a result, planning for ISDN is being reviewed continually to take these factors into consideration. It is entirely possible that Army installation information system architecture of the future may have to change significantly."

From the quoted paragraph above, in the point of view of the Army, the ISDN and LANs internetwork via TAs or gateways. The TA Approach will be the same as Approach-1: Direct Connection of Network Interface Units or Approach-2: Interconnection through Computer Ports. The Gateway Approach will be the same as Approach-3: Integrated Gateway or Approach-4: Gateway Design via a Neutral Network in Chapter 4.

We will start the discussion of the ISDN-LAN gateway design procedures using the seven steps listed in Section 5.1. The

discussion will follow the general guidelines in the paper "Army Implementation of ISDN [25]." We will describe the specific ISDN-LAN gateway design step-by-step. However, a discussion of "Step-3: Decide Which Layer Gateway Is Required" will be given first. We want to give the reasons why we choose a Layer-3 (network layer) ISDN-LAN gateway in the beginning. Then we will go back to start the discussion from Step 1.

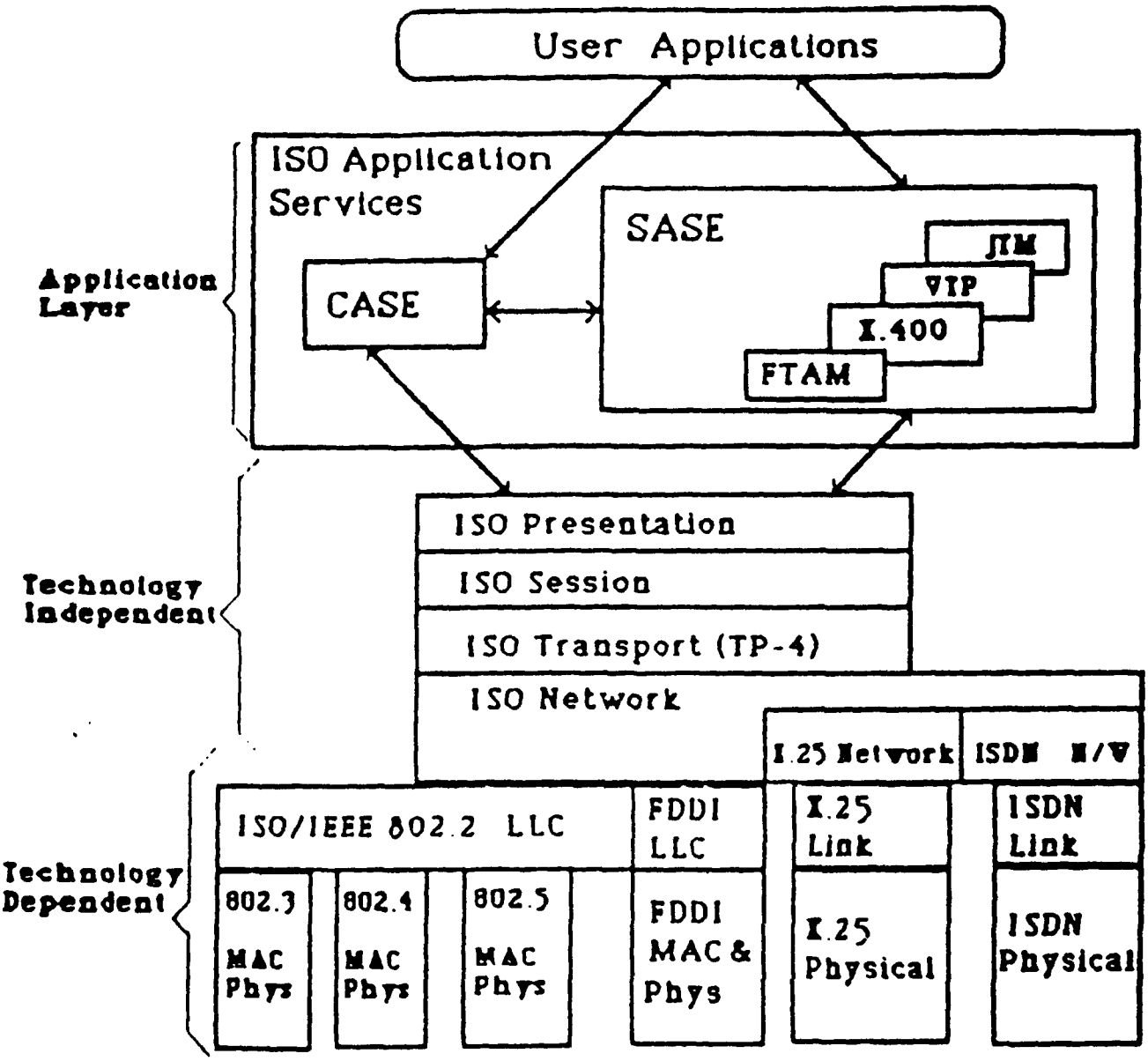
5.3 Layer 3 (Network Layer) ISDN-LAN Gateway

In Figure 2.1: ISO and CCITT OSI Seven-Layer Reference Model, we mentioned that the seven layers are subdivided into two groups. The lower group includes the physical layer, the data link layer, and the network layer. These lower three layers are concerned with packet transmission in the communication subnetwork. The upper group includes the transport layer, the session layer, the presentation layer, and the application layer. These upper four layers handle the end-to-end communications between user processes. "Figure 3.3: The Scenario of Internetworking Based on the Three-Sublayer Network-Layer Model" shows how the ISO and CCITT have tried to limit the internetworking problems in the lower three layers of the OSI reference model. The lower three layers will be different from various networks using different technologies. The ISO and CCITT assume that the higher four layers in the two communicating end-systems will be compatible. Thus the Layer-3 (network layer) gateways will be used in the world of ISO and CCITT.

Figure 5.6 shows the scenario of technology-independent upper layers and technology-dependent lower layers in the OSI seven layer reference model [27]. In Figure 5.6, the application layer is application-dependent; the presentation layer, session layer, transport layer, and the upper part of the network layer are technology independent; and the lower part of the network layer, the data link layer, and the physical layer are technology dependent. That is, the higher three layers and upper part of the network layer are software related; and the lower three layers are both software and hardware related. For example, the technologies used in the lower three layers include: CSMA/CD Ethernet (IEEE 802.3), Token Bus (IEEE 802.4), Token Ring (IEEE 802.5), Fiber Optic Cable (FDDI: Fiber Distributed Data Interface), X.25, and ISDN.

Figure 5.7 shows the layered protocol structure at the ISDN user-network interface [28]. In Figure 5.7, the lower three layers are ISDN protocols; however, the higher four layers are CCITT-ISO OSI protocols. Figure 5.7 also supports our assumption that the higher fou layers will be compatible if the two interconnected networks both use the CCITT-ISO OSI protocols. Thus our ISDN-LAN gateway design can be a Layer-3 (network layer) integrated gateway.

For the LAN side, there are a lot of different vendor's proprietary protocols. However, we believe that most LANs will follow the ISO-OSI standard protocols in the future. Especially, in the United States and worldwide eventually, the Manufacturing Automation Protocol (MAP) will be used for factory automation,



CASE: Common Application Service Elements
FDDI: Fiber Distributed Data Interface
FTAM: File Transfer, Access, and Management
ISDN: Integrated Services Digital Network
ISO: International Organization for Standardization
JTM: Job Transfer and Manipulation
LLC: Logical Link Control (Sublayer)
MAC: Media Access Control (Sublayer)
N/W: NetWork
SASE: Special Application Service Elements
TP: Transport Protocol
VTP: Virtual Terminal Protocol
X.400: CCITT Message Handling Protocol

Fig. 5.6. The Scenario of Technology-Independent Layers and Technology-Dependent Layers in the OSI Seven Layer Reference Model

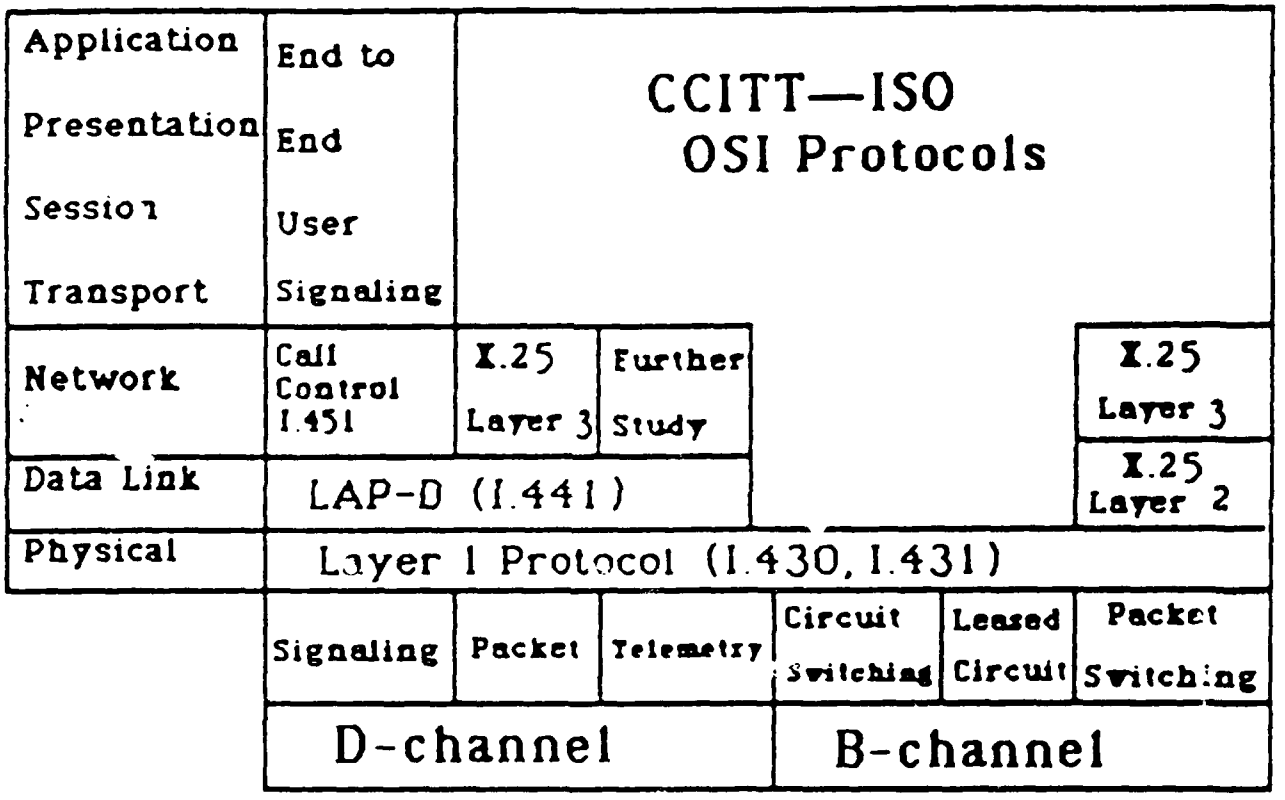


Fig. 5.7. The Layered Protocol Structure at the ISDN User-Network Interface

and the Technical and Office Protocols (TOP) will be used for office automation. So we assume our LAN protocols in this ISDN-LAN gateway design will either be MAP or TOP. From Chapter 2 Figure 2.2, we can see that the MAP and TOP are subsets of ISO-OSI standard protocols. This also matches our Layer-3 (network layer) gateway design ASSUMPTION that the higher four layers in the two end-systems should be compatible. The higher four layers in the end-system of the ISDN side and those in end-system of LAN side will use the same set of ISO-CCITT OSI standard protocols. Someone may argue that the ISDN may use different higher four layer protocols from that used by the MAP or TOP. This may be true; however, the higher four layers are usually software dependent. If the end-system is a computer, it can have several different software packages for different sets of higher four layer protocols to ensure the compatibility of the higher four layers in the end-systems. The design procedures of the ISDN-LAN gateway are discussed in the following sections.

5.4 Step-1: Understand and Use Each of the Two Networks

ISDN will provide the integrated services of voice, data, and image to users through a small set of standard user-network interfaces. LAN's, e.g., MAP or TOP in this report, usually only provide data service to users. Because users in the LAN (MAP or TOP) side do not have the digital telephones connected to the LAN, the users in the LAN side cannot access the voice service of ISDN, even there is a gateway to internetwork LAN and ISDN. This is the limitation of ISDN-LAN gateway, because the services of

ISDN and those of LAN do not match. Thus in our ISDN-LAN gateway design in this report, this ISDN-LAN gateway only provides the data service for users between ISDN and LAN.

ISDN, TOP or MAP have seven layer protocols. As we mentioned in Section 5.3, we assume that protocols of layer-4 to layer-7 in the end-systems are compatible. So our ISDN-LAN gateway design is a Layer-3 (network layer) gateway. We describe the lower three layers of ISDN, TOP, and MAP in the following section.

5.4.1. The Lower Three Layer Protocols of ISDN

The ISDN channels at the user-network interfaces are: B, D, H0, H11, H12, H4 channels. The following information was obtained from Refs. [28], [29], [30], [31].

The B, or Bearer, channel is a 64-Kbit/s bi-directional digital voice-grade (high-quality) channel that does not carry any signaling information. B channels will be the backbone of the ISDN user-network interface. They will carry voice and data using either circuit switching or packet switching.

The D channel handles both the transfer of user data and signaling information. "Signaling" refers to the passing of information for the establishment, maintenance, and clearing of ISDN channels. Traditionally, the signaling information of telephone network, such as ring, busy, and caller number, is passed along in-stream with the call (in-band signaling). The ISDN user-network interface uses "out-of-band signaling" over the D channel for more efficient transfer of data and overall use of the B channels. Since signaling occurs in bursts and is not time-consuming, the D channel will be idle for part or most of the

time. Therefore, the D channel can be used more efficiently by passing low-speed packet data and telemetry information when not in use by the signaling information for B channels. This gives a user the choice of transmitting the packet-switched data over either the B channel or the D channel. The transmission of signaling information will have a higher priority on the D channel than that of packet-switched data. Figure 5.8 shows how the B channels and D channel are to be separated and used in ISDN [25].

The H channels are formed out of multiple B channels. They will generally rely on fiber optics to support multimegabit data rates. The H channels will be used for fast facsimile, video, high-speed data, high-quality audio, and packet switching.

The transmission rates of B, D, and H channels are:

1. Basic Access Rate: 2B + D; B channel: 64 Kb/s;
   D channel: 16 Kb/s.

2. Primary Access Rate: 23B + D or 30B + D;
   B channel: 64 Kb/s;
   D channel: 64 Kb/s.

3. The H0 channel: 384 kbit/s.
   The H11 channel: 1.536 Mbit/s.
   The H12 channel: 1.920 Mbit/s.
   The H4 channel: approximately 135 Mbit/s.
   The H4 (135 Mbit/s) channel will have enough capacity to connect to high-performance LANs.

Figure 5.9 shows the layer structure of ISDN. We explain the lower three layer protocols of ISDN in the following sections. Some information on ISDN is also discussed in "Chapter 6: Internetworking DDN and ISDN."

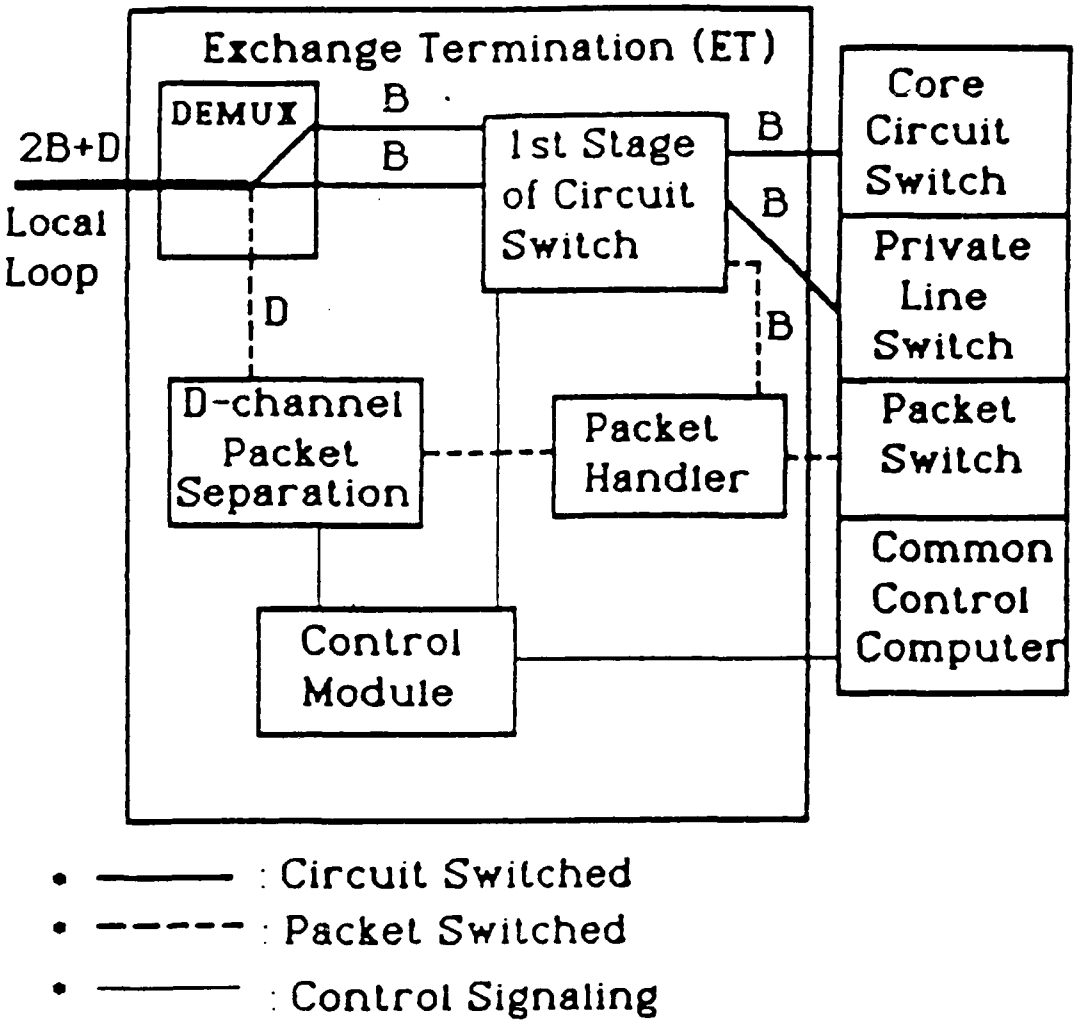


Fig. 5.8. The Exchange Termination (ET) Functional Elements of ISDN to Separate and Use B Channels and D Channel

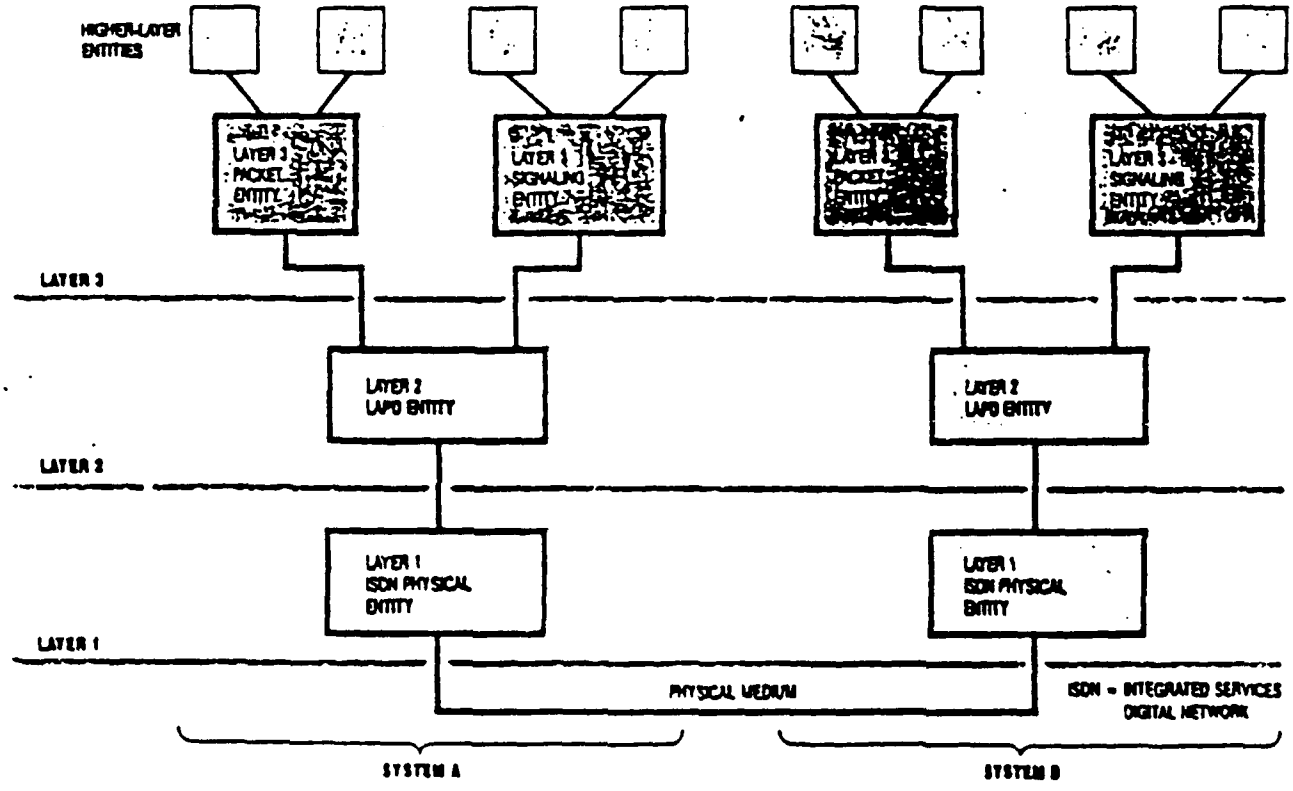
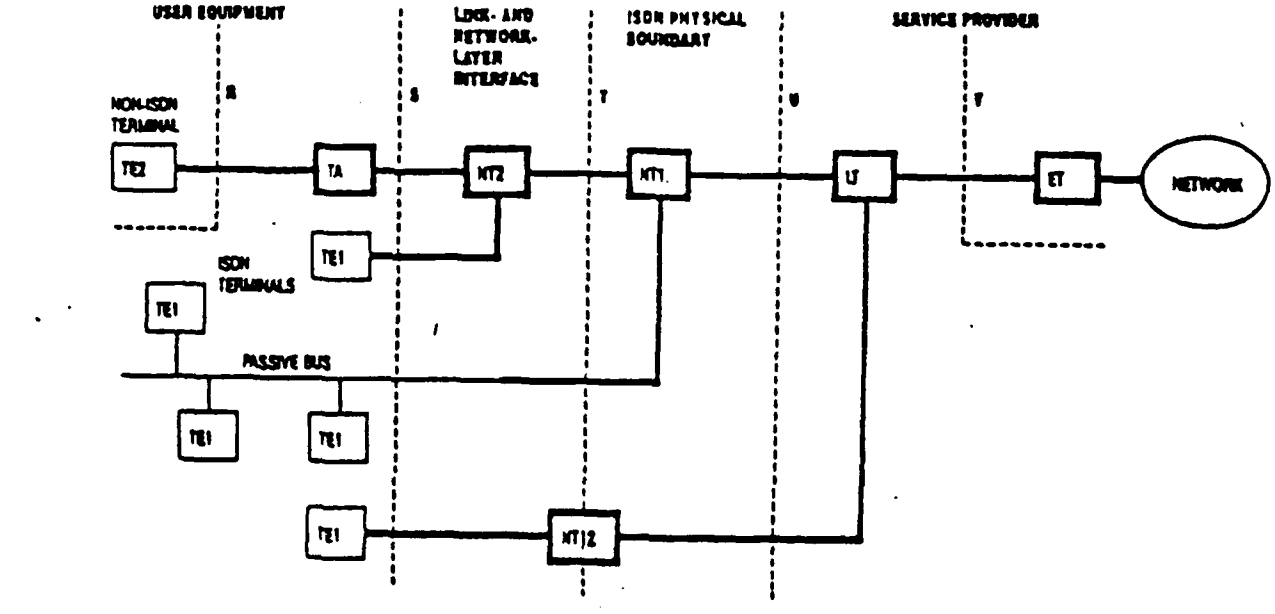


Fig. 5.9. The Layer Structure of ISDN

5.4.1.1. Layer 1 (Physical Layer) of ISDN

Figure 5.10 shows the various reference points of ISDN. The user-network interface is divided into Terminal Equipments (TEs) and Network Terminations (NTs). The access rates discussed here are: Basic Access Rate 2B + D, and Primary Access Rate 23B + D or 30B + D. Figure 5.11 shows the physical frames of ISDN Basic Access Rate. Figure 5.12 shows the physical frames of ISDN Primary Access Rate.

In Figure 5.11, although the basic-rate interface frames are the same size (48 bits), the NT frames (frames transmitted from the NT) have a different format than the TE frames (sent from the TE). This is due to the different responsibilities of the NT and the TE. In Figure 5.12, the 23B + D (1.544 Mbit/s) primary-rate interface frame is used in North America and Japan, while the 30B + D (2.048 Mbit/s) frame is used in Europe. The unit of the small rectangles in Figure 5.11 is bit, while that in Figure 5.12 is byte. There are eight bits per byte in this application.



ET = EXCHANGE TERMINATION EQUIPMENT
ISDN = INTEGRATED SERVICES DIGITAL NETWORK
LT = LINE TERMINATION EQUIPMENT
NT1 = NETWORK TERMINATION 1

NT2 = NETWORK TERMINATION 2
NT12 = COMBINED NETWORK TERMINATION 1 AND 2
R,S,T,U,V = REFERENCE POINTS
TA = TERMINAL ADAPTER

TE1 = TERMINAL EQUIPMENT TYPE 1
TE2 = TERMINAL EQUIPMENT TYPE 2

Fig. 5.10. The Various Reference Points of ISDN

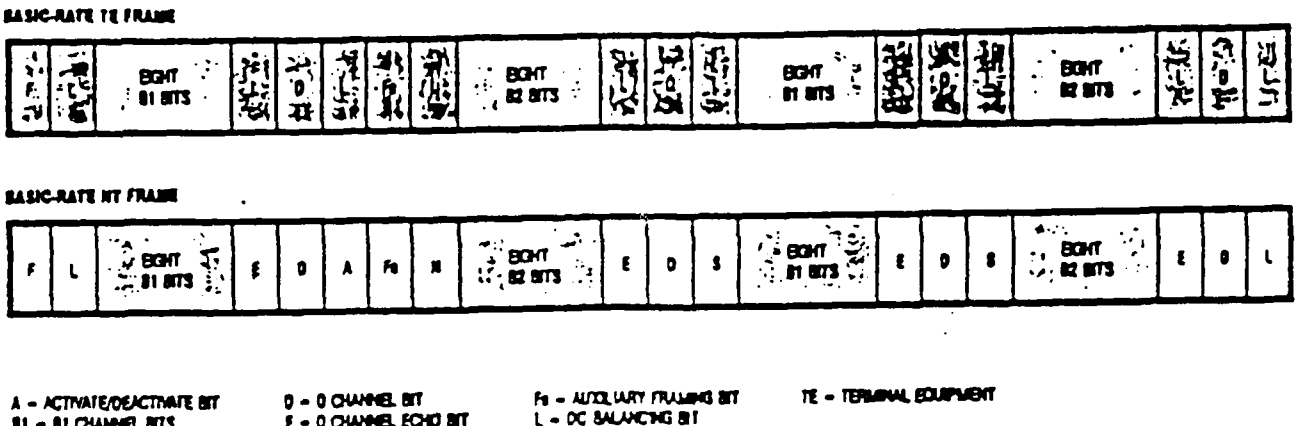


Fig. 5.11. The Physical Frames of ISDN Basic Access Rate

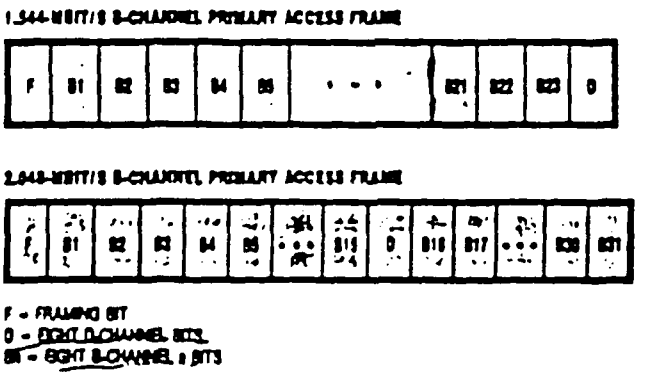


Fig. 5.12. The Physical Frames of ISDN Primary Access Rate

5.4.1.2. Layer 2 (Data Link Layer) of ISDN

Layer 2, the data link layer, is responsible for the reliable transfer of information across the physical link. Its functions include synchronization, error control, and flow control. The data link layer protocol for the signaling channel (D channel, see Figure 5.2) in ISDN is a bit-oriented protocol called LAPD, also known as CCITT Recommendation Q.921. The information transferred may be user-packet information or signaling information. Circuit-mode connections will not necessarily use LAPD for communications, except for signaling.

Figure 5.13 shows several components of ISDN LAPD frame. The LAPD frame contains a control field, Command/Response (C/R) bit, an information field, and a frame checksum. The two-byte address of each frame, called the Data Link Control Identifier (DLCI), is divided into the Service Access Point Identifier (SAPI) and the Terminal End-point Identifier (TEI). These provide a form of multiplexing. The SAPI tells the LAPD entity which Layer 3 entity the transmission is intended for. The TEI similarly identifies the logical terminal within that Layer 3 entity. The Frame Check Sequence is the standard 2-byte CCITT-16 cyclic-redundancy checksum. Finally, the frame is enveloped by one or more HDLC flags. The Command/Response (C/R) bit differentiates commands from responses.

Figure 5.14 shows the control field of ISDN LAPD. The control field indicates the type of frame being transmitted. There are three different formats for the control field: numbered information transfer (I format), supervisory functions (S

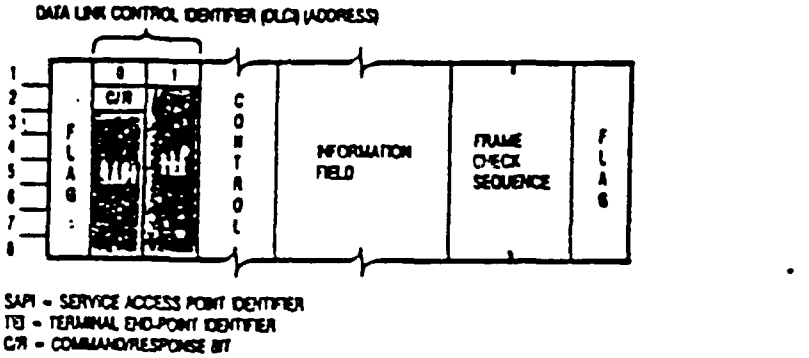


Fig. 5.13. Several Components of ISDN LAPD Frame

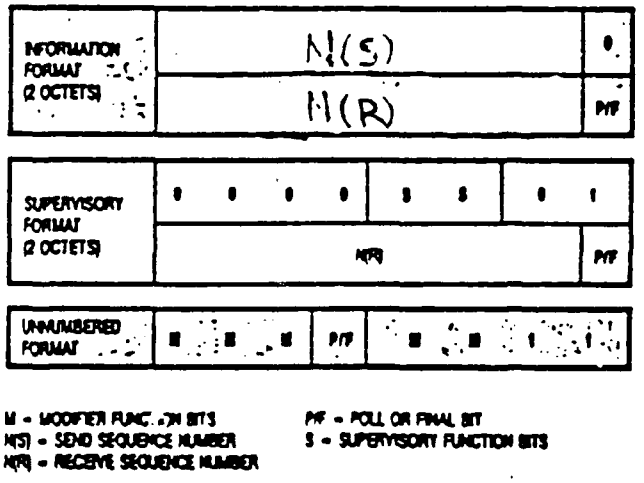


Fig. 5.14. The Control Field of ISDN LAPD

format), and unnumbered information transfers and control functions (U format). The I format helps transfer higher-layer information. The S format handles flow control. The U format helps maintain the data link connection. Figure 5.15 shows the ISDN LAPD control field types. The supervisory function bits (S bits in Figure 5.14) and modifier function bits (M bits in Figure 5.14) differentiate the LAPD frame types (listed in Figure 5.15) from one another.

FORMAT	FRAME TYPE	NAME	RESPONSIBILITY
I	I	INFORMATION	TRANSFER SEQUENTIALLY NUMBERED FRAMES CARRYING LAYER 3 INFORMATION FOR ACKNOWLEDGED INFORMATION TRANSFER SERVICE
S	RR	RECEIVER READY	INDICATES THAT THE LAYER 2 ENTITY IS READY TO RECEIVE A FRAME, ACKNOWLEDGES A PREVIOUSLY SENT FRAME, AND CLEARS THE BUSY CONDITION ESTABLISHED BY AN RNR FRAME
	RNR	RECEIVER NOT READY	INDICATES A LINK LAYER BUSY CONDITION (A TEMPORARY INABILITY TO ACCEPT INCOMING I FRAMES)
	REJ	REJECT	REQUEST RETRANSMISSION OF I FRAMES STARTING AT THE N(R) FRAME
U	SABME	SET ASYNCHRONOUS BALANCED MODE EXTENDED	BEGIN LINK CONNECTION FOR ACKNOWLEDGED INFORMATION TRANSFER SERVICE USING MODULO 128 FRAME WINDOWING
	DM	DISCONNECT MODE	INFORMS RECEIVING ENTITY THAT THE CONNECTION IS IN AN ERROR STATE AND THAT UNACKNOWLEDGED INFORMATION TRANSFER SERVICE CANNOT BE PERFORMED
	UI	UNNUMBERED INFORMATION	UNNUMBERED FRAMES CARRYING LAYER 3 INFORMATION FOR UNACKNOWLEDGED INFORMATION TRANSFER SERVICE
	DISC	DISCONNECT	USED TO TERMINATE ACKNOWLEDGED INFORMATION TRANSFER SERVICE
	UA	UNNUMBERED ACKNOWLEDGMENT	ACKNOWLEDGE SABME OR DISC
	FRMR	FRAME REJECT	REPORT OF AN ERROR CONDITION THAT CAN NOT BE RECOVERED BY THE RETRANSMISSION OF AN IDENTICAL FRAME
	XID	TRANSFER ID	USED TO TRANSFER CONNECTION MANAGEMENT INFORMATION BETWEEN PEER ENTITIES

Fig. 5.15. The ISDN LAPD Control Field Types

5.4.1.3. Layer 3 (Network Layer) of ISDN

There are three mutually exclusive scenarios for using the ISDN network layer protocols of D channel and B channel [32].

1. Circuit mode connections over the user-data B channels.
   Figure 5.16 shows the network configuration and protocols for the circuit switching scenario.
2. Packet switching using B channel with circuit-switched access.
   Figure 5.17 shows network configuration and protocols for packet switching using B channel with circuit-switched access.
3. Packet mode connections over D channel.
   Figure 5.18 shows network configuration and protocols for packet switching for D channel.

Figure 5.19 explains the terminologies used in Figure 5.16, Figure 5.17, and Figure 5.18. All three scenarios use the ISDN layer 3 protocol over D channel. Packet-Switching Facilities (PSFs) are used for handling data transmission over packet switching network.

The Draft Proposal (DP) of ISO/TC97/SC6 4350 (02/02/1987) also discussed some relationships between the ISDN protocols and ISO protocols. The title of ISO/TC97/SC6 DP4350 is [33]:

> "Draft of an ISO standard on provision of the OSI connection-mode network service by packet mode terminal equipment connected to an Integrated Service Digital Network (ISDN)."

Figure 5.20 shows the protocol layers at S and T Reference Points when D channel is used in ISDN. Figure 5.21 shows protocol layers at S and T Reference Points when B channel is used in ISDN.

The ISDN's layer 3, the network layer, has not been completed to the degree of the physical and data link layers. The network

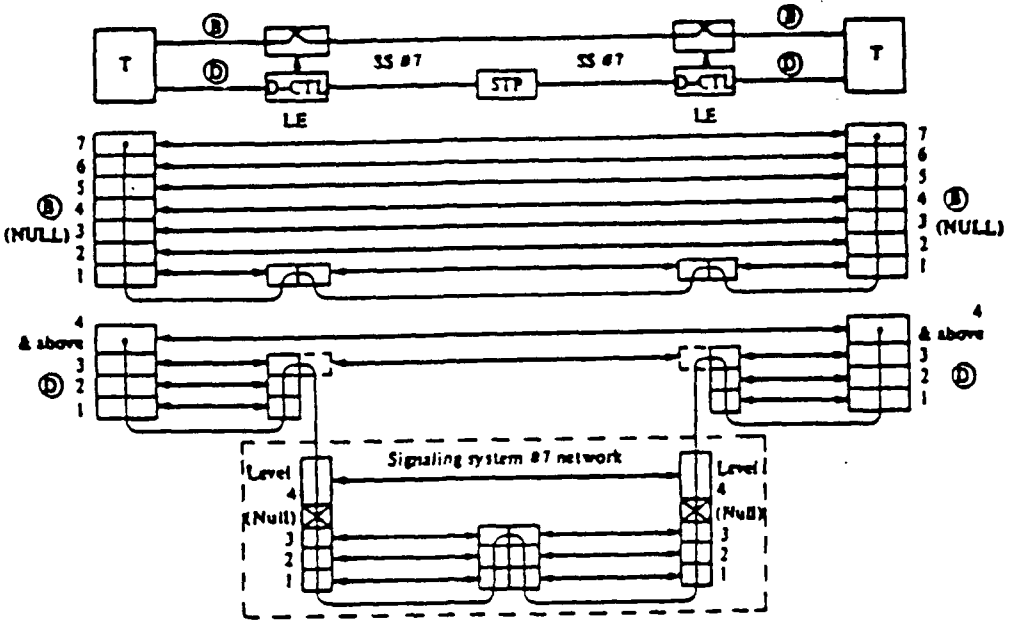


Fig. 5.16. The Network Configuration and Protocols for the ISDN Circuit Switching Scenario

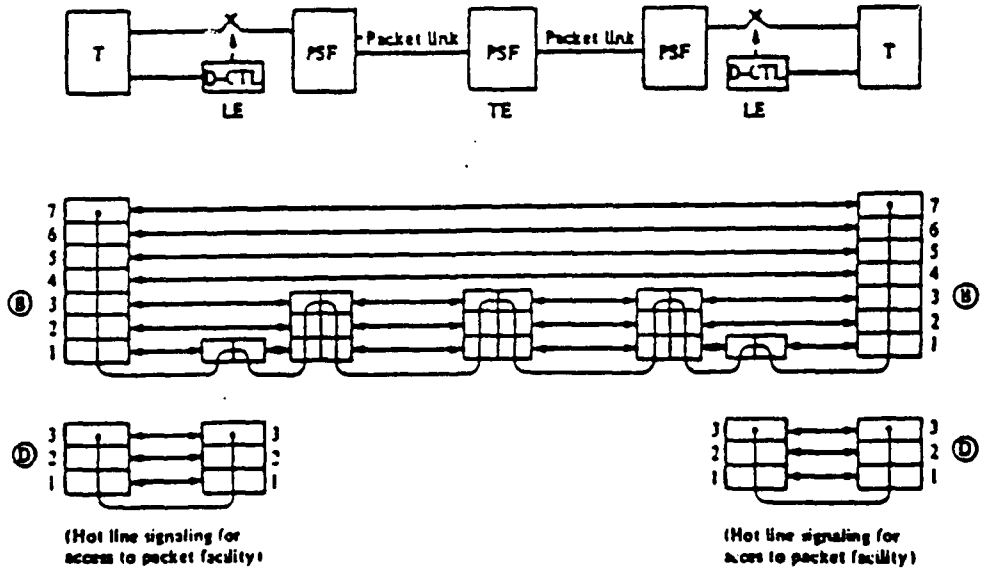


Fig. 5.17. The Network Configuration and Protocols for Packet Switching Using B Channel with Circuit-Switched Access

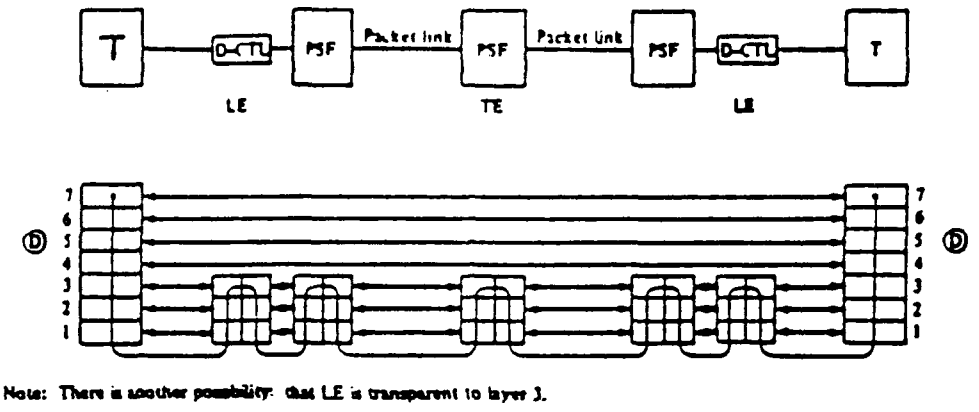


Fig. 5.18. The Network Configuration and Protocols for Packet Switching Using D Channel

B	=	An ISDN B channel
D	=	An ISDN D channel
T	=	Terminal
D-CTL	=	D-channel controller
SS 7	=	CCITT signaling system 7
STP	=	Signaling transfer point
(Null)	=	*Channel not present*
7, 6, 5, 4, 3, 2, 1	=	Layers in ISO basic reference model
LEVEL	=	Levels in SS 7
LE	=	Local exchange
TE	=	Transit exchange
PSF	=	Packed-switching facility
Horizontal line	=	Peer-to-peer protocol
Vertical line	=	Layer-to-layer data flow

Fig. 5.19. The Terminologies Used in Figures 5.16, 5.17, and 5.18.

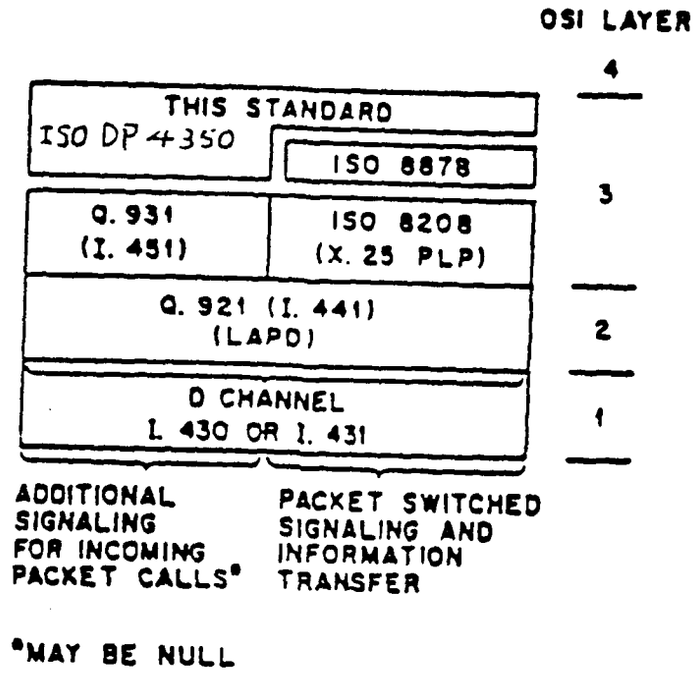


Fig. 5.20. The Protocol Layers at S and T Reference Points When D Channel Is Used in ISDN

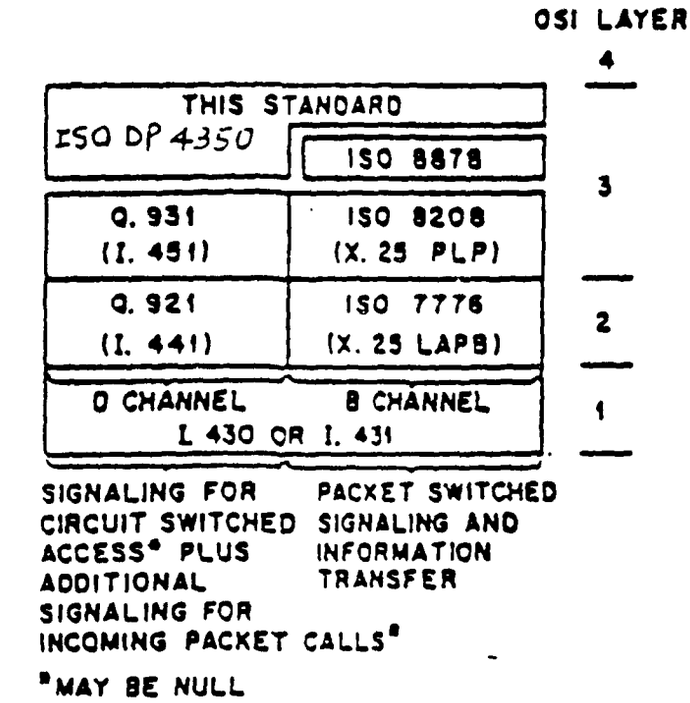


Fig. 5.21. The Protocol Layers at S and T Reference Points When B Channel Is Used in ISDN

layer protocol of ISDN, known by its CCITT Recommendation Q.931, must be able to both handle data transport and signaling. The Network Layer Protocol Q.931 uses messages to convey information between two Layer 3 entities. The components of the message are called information elements. Figure 5.22 shows the ISDN Q.931 Network Layer message format. Q.931 message format includes the protocol discriminator, call-reference flag and value, message type, mandatory and optional information elements. Some of the optional information elements are shown in Figure 5.23. Figure 5.24 shows the format of the optional ISDN network layer information elements. The optional ISDN network layer information elements transport the facilities and maintenance information about a network layer call.

In Figure 5.22, the protocol discriminator is used to distinguish an ISDN network message from other OSI network layer messages. The protocol discriminator is always the first byte of a Q.931 message. The call reference is the second information element in Q.931 message. It is used to identify the message with a connection request. The call reference is made up of call-reference length, a call-reference flag, and a call-reference value. The third element in Q.931 is message type. The message type identifies the function of the message being transmitted. Message types are divided into one of the three categories: call-establishment, call-disestablishment, and miscellaneous messages. Figure 5.25 shows the selected ISDN network-layer message types.

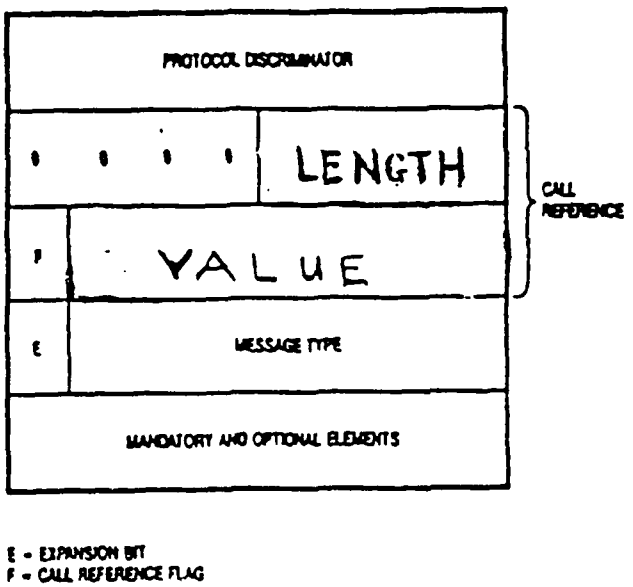


Fig. 5.22. The ISDN Q.931 Network Layer Message Format

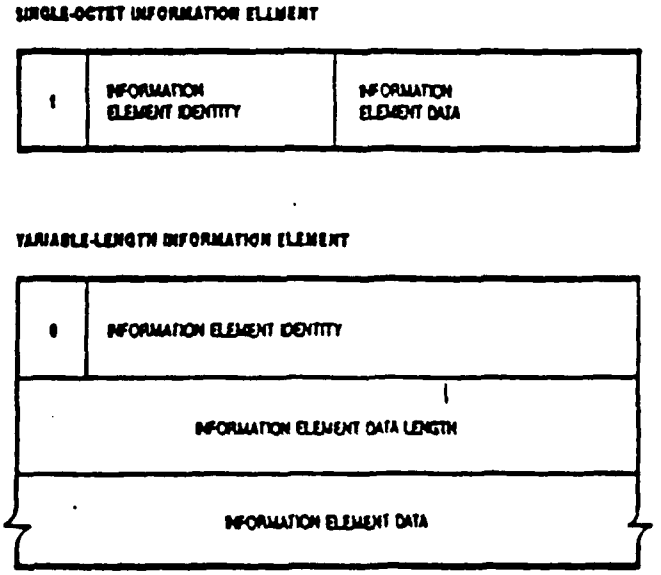


Fig. 5.24. The Format of the Optional ISDN Q.931 Information Elements

SINGLE-OCTET INFORMATION ELEMENT	
NAME	FUNCTION
LOCKING SHIFT	INDICATES THAT THE FOLLOWING IS DIFFERENT TYPE OF INFORMATION ELEMENT (GIVES THE ABILITY TO SHIFT BETWEEN INTERNATIONAL, NATIONAL, NETWORK-SPECIFIC, AND USER-SPECIFIC INFORMATION ELEMENTS)
VARIABLE-LENGTH INFORMATION ELEMENTS	
NAME	FUNCTION
BEARER CAPABILITY	INDICATES THAT THE NETWORK CAN PROVIDE SPECIFIC BEARER CAPABILITIES (DATA TRANSFER RATE, DATA TRANSFER CAPABILITY)
CALL STATE	DEFINES CURRENT STATE OF CONNECTION (SUCH AS ACTIVE, DETACHED, AND DISCONNECT REQUEST)
CHANNEL IDENTIFICATION	IDENTIFY CHANNEL/SUBCHANNEL WITHIN THE INTERFACE
PROGRESS INDICATOR	DESCRIBES AN EVENT THAT OCCURRED DURING A CALL
KEYPAD	MECHANISM TO TRANSPORT IA5 (INTERNATIONAL ALPHABET 5, ALSO KNOWN AS ASCII) CHARACTERS - ENTERED BY MEANS OF A TERMINAL KEYPAD
CALLING PARTY NUMBER	IDENTIFIES SOURCE OF A CALL
CALLED PARTY NUMBER	IDENTIFIES DESTINATION OF A CALL
TRANSIT NETWORK SELECTOR	IDENTITY OF A NETWORK THAT CONNECTION SHOULD USE TO GET TO FINAL DESTINATION
LOW-LAYER COMPATIBILITY	USED FOR COMPATIBILITY CHECKING, IN CONJUNCTION WITH BEARER CAPABILITY
USER-USER INFORMATION	USED TO TRANSFER INFORMATION BETWEEN ISDN USERS THAT SHOULD NOT BE INTERPRETED BY THE NETWORK(S). EQUIVALENT TO FAST SELECT IN X.25

Fig. 5.23. The Optional Information Elements of ISDN Q.931

NAME	DEFINITION
CALL ESTABLISHMENT MESSAGES	
ALERTING	RECEPTION OF A SETUP MESSAGE
CALL PROCEEDING (CALL PROC)	CALL ESTABLISHMENT HAS BEGUN AND NO MORE INFORMATION IS NEEDED
CONNECT (CONN)	CALL ACCEPTANCE BY CALLED USER
CONNECT ACKNOWLEDGE (CONN ACK)	RECEIPT OF CONNECT MESSAGE
SETUP	BEGIN CALL ESTABLISHMENT
SETUP ACKNOWLEDGE (SETUP ACK)	CALL ESTABLISHMENT HAS BEGUN AND MORE INFORMATION IS NEEDED BEFORE PROCEEDING
CALL DISESTABLISHMENT MESSAGES	
DISCONNECT (DISC)	INVITATION TO RELEASE A CHANNEL AND ALL ASSOCIATED CALL-REFERENCE VALUES
RELEASE (REL)	SENDING SIDE HAS RELEASED A CHANNEL AND ALL ASSOCIATED CALL REFERENCE VALUES; SENDING SIDE SHOULD DO THE SAME IF IT HAS NOT ALREADY DONE SO
RELEASE COMPLETE (REL COM)	SENDING SIDE HAS RELEASED A CHANNEL AND CONSIDERS THAT CHANNEL TO BE READY FOR REUSE
RESTART (REST)	REQUEST THAT A CHANNEL BECOME IDLE
RESTART ACKNOWLEDGE (REST ACK)	INDICATES REQUESTED RESTART IS COMPLETE
MISCELLANEOUS MESSAGES	
INFORMATION (INFO)	PROVIDE ADDITIONAL INFORMATION FOR CALL ESTABLISHMENT
STATUS (STAT)	RESPONSE TO UNEXPECTED MESSAGE OR IN RESPONSE TO A STATUS ENQUIRY
STATUS ENQUIRY (STAT ENQ)	SOLICIT INFORMATION ABOUT THE STATE OF THE CONNECTION

Fig. 5.25. The Selected ISDN Q.931 Message Types

5.4.2 The Lower Three Layer Protocols of TOP and MAP

We show "Figure 2.2: MAP Version 2.1 and TOP Version 1.0" as Figure 5.26 here for easy reference. Although the MAP and TOP contain seven layer protocols, we discuss just the lower three layer protocols which are related to this layer-3 (network layer) ISDN-LAN (TOP or MAP) gateway design. The only difference of lower three layers between MAP and TOP is in Layer 1. The MAP's Layer 1 is IEEE 802.4 Broadband Token-Passing Bus. The Layer 1 of TOP is IEEE 802.3 CSMA/CD Ethernet. The Layer 2 of MAP and TOP is IEEE 802.2 Logical Link Control (LLC) Type 1, Class 1. The Layer 3 of MAP and TOP is ISO Internet Protocol (IP) 8473. From Section 5.2 Army Implementation of ISDN [25], in the environment of U.S. Army Information Systems Command, the Army policy is to use LANs that meet the IEEE 802.3 standard. That is, TOP protocol is more suitable for Army's LAN applications.

5.4.2.1. Layer 1 (Physical Layer) of MAP and TOP

In the IEEE 802 LAN standards, the OSI layer 2 (data link layer) is subdivided into two sublayers: Logical Link Control (LLC) Sublayer and Media Access Control (MAC) Sublayer. However, ISO is considering to move the IEEE defined MAC Sublayer to the physical layer (layer 1). So the TOP's layer 1 is IEEE 802.3 Ethernet, and the MAP's Layer 1 is IEEE 802.4 Broadband Token-Passing Bus. Figure 5.27 shows the frame formats of IEEE 802.3 CSMA/CD and IEEE 802.4 Token Bus [34]. CSMA/CD means Carrier Sense Multiple Access with Collision Detection.

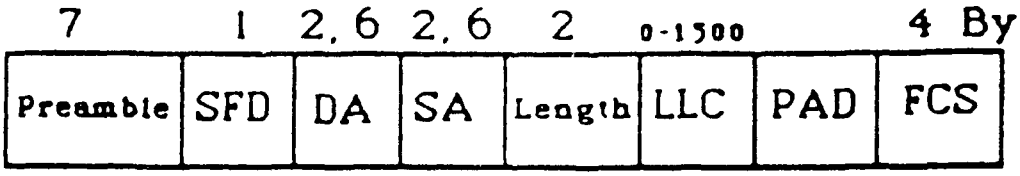
Layer	TOP Version 1.0 Protocols	MAP Version 2.1 Protocols
7	ISO FTAM (DP) 8571 File Transfer, limited file management (ASCII and binary data only)	ISO FTAM (DP) 8571 File Transfer Protocol Manufacturing Messaging Format Standard (MMFS) Common Application Service Elements (CASE)
6	Null* (ASCII and binary encoding)	
5	ISO Session (IS) 8327 Session kernel, full duplex	
4	ISO Transport (IS) 8073 Class 4	
3	ISO Internet (DIS) 8473 Connectionless and for X.25-Subnetwork dependent convergence protocol (SNDCP)	
2	ISO Logical Link Control (DIS) 8802/3 (IEEE 802.2) Type 1, Class 1	
1**	ISO CSMA/CD (DIS) 8802/3 (IEEE 802.3) CSMA/CD media access Control, 10Base 5	ISO Token-passing bus (DIS) 8802/4 (IEEE 802.4) Token-passing bus media access control

* A null layer provides no additional services but exists only to provide a logical path for the flow of network data and control

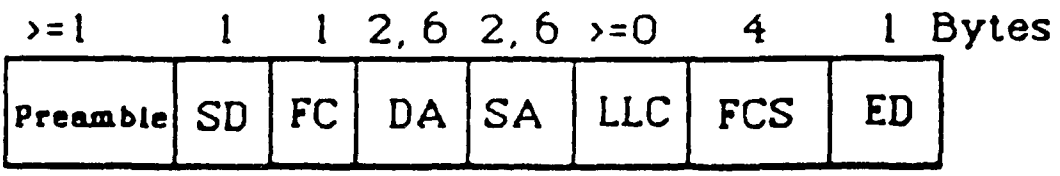
** ISO is considering moving the IEEE defined media access control (MAC) sublayer of the data link layer (Layer 2) to the physical layer (Layer 1)

Fig. 5.26. MAP Version 2.1 and TOP Version 1.0

IEEE 802.3 CSMA/CD



IEEE 802.4 Token Bus



DA: Destination Address
ED: Ending Delimiter
FC: Frame Control
FCS: Frame Check Sequence
LLC: Logical Link Control
SA: Source Address
SD: Starting Delimiter

Fig. 5.27. The Frame Formats of IEEE 802.3 CSMA/CD and IEEE 802.4 Token Bus

In Figure 5.27, the individual fields of IEEE 802.3 CSMA/CD standard are [34]:

1. Preamble: a 7-byte pattern used by the receiver to establish bit synchronization and then locate the first bit of the frame.
2. Start Frame Delimiter (SDF): indicates the start of a frame.
3. Destination Address (DA): specifies the station for which the frame is intended. The choice of a 16-bit or 48-bit address is an implementation decision, and must be the same for all stations on a particular LAN.
4. Source Address (SA): specifies the station that sent the frame. The SA size must equal the DA size.
5. Length: Specifies the number of LLC bytes that follow.
6. LLC: field prepared at the LLC (Logical Link Control) level.
7. Pad: a sequence of bytes added to assure that the frame is long enough for proper CD (Collision Detection) operation.
8. Frame Check Sequence (FCS): a 32-bit cyclic redundancy check value. Based on all fields, starting with destination address.

In Figure 5.27, the individual fields of IEEE 802.4 Token Bus standard are [34]:

1. Preamble: a one or more byte pattern used by receivers to establish bit synchronization and locate the first bit of the frame.
2. Start Delimiter (SD): indicates start of frame.
3. Frame Format (FC): indicates whether this is an LLC data frame. If not, bits in this field control operation of the token bus MAC protocol. An example is a token frame.

4. Destination Address (DA): same as the CSMA/CD.
5. Source Address (SA): same as the CSMA/CD.
6. LLC: field prepared by LLC.
7. Frame Check Sequence (FCS): same as the CSMA/CD.
8. End Delimiter (ED): indicates end of frame.

5.4.2.2. Layer 2 (Data Link Layer) of MAP and TOP

Figure 5 28 shows the IEEE 802.2 Logical Link Control (LLC) frame format. Figure 5.29 shows the IEEE 802.2 LLC Control Field Format. As with High-level Data Link Control (HDLC), three frame formats are defined for IEEE 802.2 LLC: Information (I) format, Supervisory (S) format, and Unnumbered (U) format. Their use depends on the type of operation employed. There are three types of LLC operations: Type 1 (connectionless), Type 2 (connection-oriented), and Type 3 (acknowledged connectionless). Figure 5.30 shows the Logical Link Control (LLC) Primitives of User-LLC Interface.

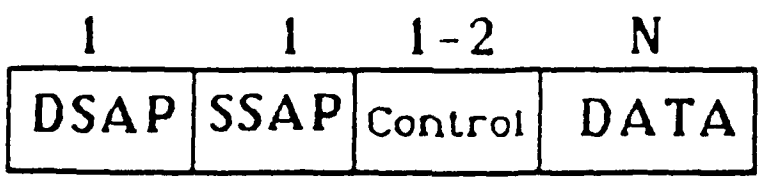
The IEEE 802.2 LLC is intended to operate with any of the three MAC protocols: 802.3 CSMA/CD, 802.4 Token Bus, and 802.5 Token Ring. A single logical interface to any of the MAC layers is defined. The basic primitives of the LLC-MAC interface are:

1. MA-DATA.request: to request transfer of an LLC frame from local LLC to destination LLC. This includes information transfer, supervisory, and unnumbered frames.
2. MA-DATA.confirm: response from local MAC layer to LLC's MA-DATA.request. It indicates the success or failure of the

request.

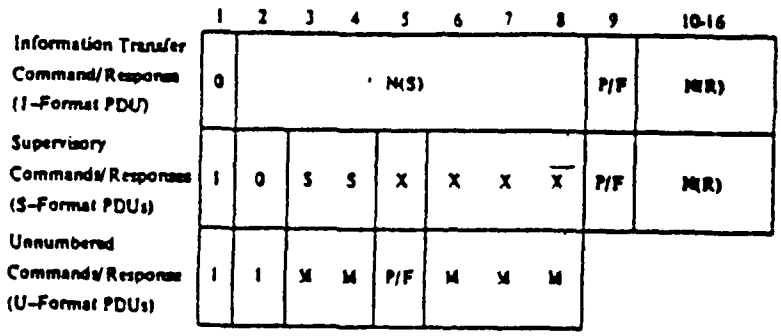
3. MA-DATA.indicate: to transfer incoming LLC frame from local MAC to local LLC.

IEEE 802.2 Logical Link Control (LLC)



DSAP: Destination Service Access Point
SSAP: Source Service Access Point

Fig. 5.28. The IEEE 802.2 LLC Frame Format



Where

N(S)–Transmitter Send Sequence Number (Bit 3–Low-order Bit)
N(R)–Transmitter Receive Sequence Number (Bit 10–Low-order Bit)
S–Supervisory Function Bit
M–Modifier Function Bit
X–Reserved and Set to Zero
P/F–Poll Bit–Command LLC PDU Transmissions
Final Bit–Response LLC PDU Transmissions
(1–Poll/Final)

Fig. 5.29. The IEEE 802.2 LLC Control Field Format

Unacknowledged Connectionless Service

L_DATA.request (local_address,remote_address,l_sdu,service_class)
L_DATA.indication (local_address,remote_address,l_sdu,service_class)

Connection-oriented Service

L_DATA_CONNECT.request (local_address,remote_address,l_sdu)
L_DATA_CONNECT.indication (local_address,remote_address,l_sdu)
L_DATA_CONNECT.confirm (local_address,remote_address,status)

L_CONNECT.request (local_address,remote_address,service_class)
L_CONNECT.indication (local_address,remote_address,status,service_class)
L_CONNECT.confirm (local_address,remote_address,status,service_class)

L_DISCONNECT.request (local_address,remote_address)
L_DISCONNECT.indication (local_address,remote_address, reason)
L_DISCONNECT.confirm (local_address,remote_address,status)

L_RESET.request (local_address,remote_address)
L_RESET.indication (local_address,remote_address,reason)
L_RESET.confirm (local_address,remote_address,status)

L_CONNECTION_FLOWCONTROL.request (local_address,remote_address,amount)
L_CONNECTION_FLOWCONTROL.indication (local_address,remote_address,amount)

Acknowledged Connectionless Service

L_DATA_ACK.request (local_address,remote_address,l_sdu,service_class)
L_DATA_ACK.indication (local_address,remote_address,l_sdu,service_class)
L_DATA_ACK_STATUS.indication (local_address,remote_address,service_class,status)

L_REPLY.request (local_address,remote_address,l_sdu,service_class)
L_REPLY.indication (local_address,remote_address,l_sdu,service_class)
L_REPLY_STATUS.indication (local_address,remote_address,l_sdu,service_class,status)

L_REPLY_UPDATE.request (local_address,l_sdu)
L_REPLY_UPDATE_STATUS.indication (local_address,status)

Fig. 5.30. The IEEE 802.2 LLC Primitives for User-LLC Interface

5.4.2.3 Layer 3 (Network Layer) of MAP and TOP

The layer 3 (network layer) of MAP and TOP is ISO IS 8473 Internet Protocol (IP). The MAP uses Token-Passing Bus, and the TOP uses CSMA/CD Ethernet. Both MAP and TOP use BUS topology. For the bus topology, the Layer 3 (Network Layer) can be absent if we do not consider internetworking with other networks. However, MAP and TOP foresee the necessity of internetworking with other networks. So both MAP and TOP use ISO Internet Protocol (IP) as their Layer 3 protocol.

The ISO IP exhibits minor differences from DoD IP. Figure 5.31 shows the ISO IP Header format. Figure 5.32 shows the DoD IP Header format. We discuss the ISO IP Header first. Then the differences between ISO IP and DoD IP will be discussed.

In Figure 5.31, the ISO IP header is largely self-explanatory. Some clarifying remarks are as follows:

1. Protocol Identifier: When the source and destination stations are connected to the same network, an internet protocol is not needed. In that case the internet layer is null and the header consists of this single field of 8 bits.
2. PDU Lifetime: Expressed as a multiple of 500 ms. It is determined and set by the source station. Each gateway that the IP datagram visits decrements this field by 1 for each 500 ms of estimated delay for that hop. When the lifetime value reaches 0, the datagram is discarded. This technique prevents endlessly circulating datagrams.
3. Flags: The S/P flag indicates whether segmentation is permitted. The M/S flag is the more flag. The E/P flag

Name	Size (bits)	Purpose
Protocol Identifier	8	Indicates if internet service is provided
Header Length	8	Header length in octets
Version	8	Version of protocol
PDU Lifetime	8	Lifetime in units of 500 ms
Flags	3	Three one-bit indicators
Type	5	Data or Error PDU
Segment Length	16	Header plus data length
Checksum	16	Applies to header only
Destination Address Length	8	Length of field in octets
Destination Address	Variable	Structure not specified
Source Address Length	8	Length of field in octets
Source Address	Variable	Structure not specified
Identifier	16	Unique for source, destination
Segment Offset	16	Offset in octets
Total Length	16	Length of original PDU
Options	Variable	Additional services

Fig. 5.31. The Header Format of ISO Internet Protocol (IP)

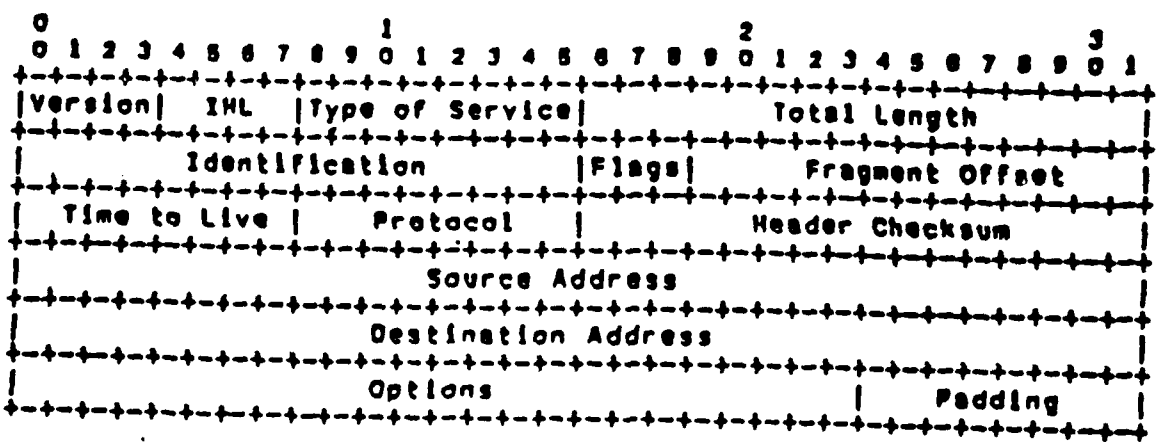


Fig. 5.32. The Header Format of DoD Internet Protocol (IP)

indicates whether an error report is desired by the source station if a datagram is discarded.

4. Checksum: Computed at each gateway.
5. Addresses: Variable-length addresses are provided; the structure of the addresses is not specified in the standard.
6. Options: The optional parameters that may be specified include: Security, defined by the user; Source Routing, which allows the source station to dictate the gateway routing; Recording of Route, used to trace the route a datagram takes; Priority; and Quality of Service, which specifies reliability and delay parameters.

The ISO IP provides a connectionless data transfer service to IP users, e.g., Transport Protocol (TP), in hosts attached to networks of the internet. Three primitives are defined at the user (TP)-IP interface. The DATA.request primitive is used to request transmission of a data unit. DATA.indication is used by IP to notify a user of the arrival of a data unit. An ERROR primitive may be used to notify a user of failure to deliver a datagram. For these primitives, the following parameters are used: destination address, source address, options, and user data.

5.4.2.4. The Differences Between ISO IP and DoD IP

By comparing Figure 5.31 ISO IP header with Figure 5.32 DoD IP header, several differences between ISO IP and DoD IP can be found. Those differences are:

1. Addresses: The DoD IP uses fixed 32-bit address length. The ISO IP uses variable addresses. In ISO IP header, two

fields: address length (8-bit) and address (variable) are used to specified the address of a station.

2. Lifetime of Datagram: The unit of lifetime in ISO IP is 500 ms. The unit of Time To Live of datagram in DoD IP is second.
3. Error Reporting: In DoD IP, another protocol, Internet Control Message Protocol (ICMP), is used for error reporting.
   In ISO IP header, the field Type (5-bit) indicates Data or Error Protocol Data Unit (PDU). That is, the ISO IP has the error reporting capability in its header.
4. Flags: Both ISO IP and DoD IP have three flags. However, the usage of flags is different between ISO IP and DoD IP.
   The third bit flag is the E/P flag of ISO IP to indicate whether an error report is desired by the source station if a datagram is discarded.
   In the DoD IP, the third bit flag is not used.
5. Header Length: In the DoD IP, the Internet Header Length (IHL, 4-bit) indicates the length of header in 32-bit words.
   In the ISO IP, the Header Length (8-bit) indicates the length of IP header in bytes.
6. Version: The Version field of the DoD IP is 4-bit.
   The Version field of the ISO IP is 8-bit.
7. Protocol Identifier: The ISO IP uses this Protocol Identifier to indicate whether the source station and the destination station in the same network or in different networks.
   The DoD IP has Protocol field (8-bit) to indicate the next higher layer protocol which is to receive the data field at

the destination.

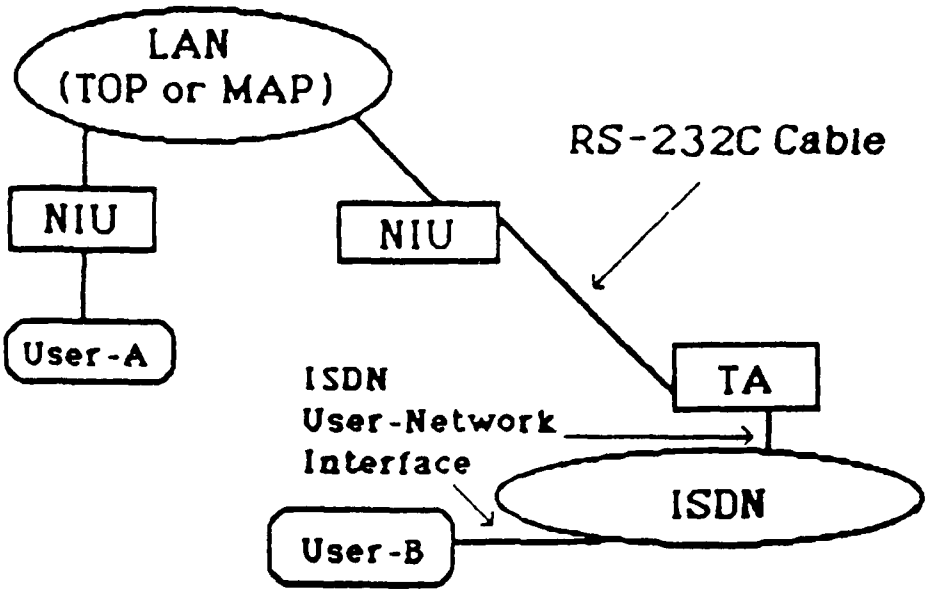
8. Total Length: In DoD IP, the Total Length field (16-bit) indicates total data unit length, including header, in bytes. In ISO IP, there are two fields: Segment Length field (16-bit) and Total Length field (16-bit). The Segment Length field indicates the header plus data length of that segment. The Total Length field of ISO IP indicates length of the original PDU.

9. Segment Offset: In the DoD IP, the Fragment Offset field (13-bit) indicates where in the datagram this fragment belongs. It is measured in 64-bit units. This implies that fragments (other than the last fragment) must contains a data field that is a multiple of 64 bits long.
   In the ISO IP, the Segment Offset field (16-bit) indicates where in the datagram this segment belongs. It is measured in bytes. That is, the segmentation in bytes of ISO IP is more flexible than the fragmentation in 64-bit units of DoD IP.

5.5. Step 2: Start Internetworking from Approach-1 and Approach-2

In the Section 5.2 Army Implementation of ISDN, generally it has been assumed that LANs will interface with ISDN through Terminal Adapters (TAs) or gateways. The TA approach of ISDN-LAN internetworking is basically the same as our "Approach-1: Direct Connection of Network Interface Units," or "Approach-2: Interconnection through Computer Ports." Figure 5.33 shows the scenario of ISDN-LAN internetworking through LAN Network Interface Unit (NIU) and ISDN Terminal Adapter (TA).

In the Integrated Services Digital Network (ISDN), the digital equipments with ISDN interfaces can directly plug into ISDN socket without Modem. However, existing digital equipments, such as computers or terminals, usually uses non-ISDN interfaces, e.g., RS-232C ports. The existing digital equipments with non-ISDN interfaces cannot connect ISDN directly. They must connect ISDN through Terminal Adapters (TAs). A TA for ISDN is a protocol converter. One side of the TA provides ISDN S Reference Point Interface, the other side of TA provides non-ISDN interface such as RS-232C port. The TA performs: (i) bit rate adaption; (ii) signaling conversion (mapping) between RS-232C and the Q.931 D-channel procedures; (iii) ready for data alignment [35]. Some reports predict that when ISDN becomes popular, a lot of today's Modem manufacturers will become Terminal Adapter (TA) manufacturers.



NIU: Network Interface Unit
TA: Terminal Adapter

Fig. 5.33. The Scenario of ISDN-LAN Internetworking through LAN Network Interface Unit (NIU) ISDN Terminal Adapter (TA)

5.6. Step 3: Decide Which Layer Gateway Is Required

We have given the reasons why we chose the Layer-3 (network layer) ISDN-LAN gateway design in "Section 5.3: Layer-3 ISDN-LAN Gateway." Thus we just show "Figure 5.34: the Layer Structure of the Layer 3 ISDN-LAN Gateway" here. The lower three layer protocols of ISDN, TOP, and MAP were discussed in "Section 5.4: Understand and Use Each of the Two Networks."

5.7. Step 4: Obtain the Required Information from Network Vendors

We described the lower three layer protocols of ISDN, MAP, and TOP in "Section 5.4: Understand and Use Each of the Two Networks." Thus here "the required information from network vendors" means the information of VLSI chips and the communication adapter boards for ISDN, MAP, or TOP.

Figure 5.35 shows the available ISDN VLSI chips from several companies [36]. This information is based on "The Universal Data Connection," IEEE Spectrum, July 1987. There should be more ISDN VLSI chips available now than the information in Figure 5.35. For the TOP LAN, Intel Corp. has IEEE 802.3 CSMA/CD VLSI chip and the Ethernet communication adapter boards and software available. For the MAP LAN, Motorola Co. has IEEE 802.4 Token Bus VLSI chip; and several LAN vendors announced the MAP communication adapter boards and software available. Actually, one big benefit of standard protocols, such as ISDN, TOP, and MAP, is that more and more companies will commit and produce products followed the standard protocols. For this ISDN-LAN (TOP or MAP) gateway design, there will be a lot of off-the-shelf software and

hardware for ISDN, TOP, and MAP available. The commercial ISDN-LAN (TOP or MAP) gateways may be available in the future, too.

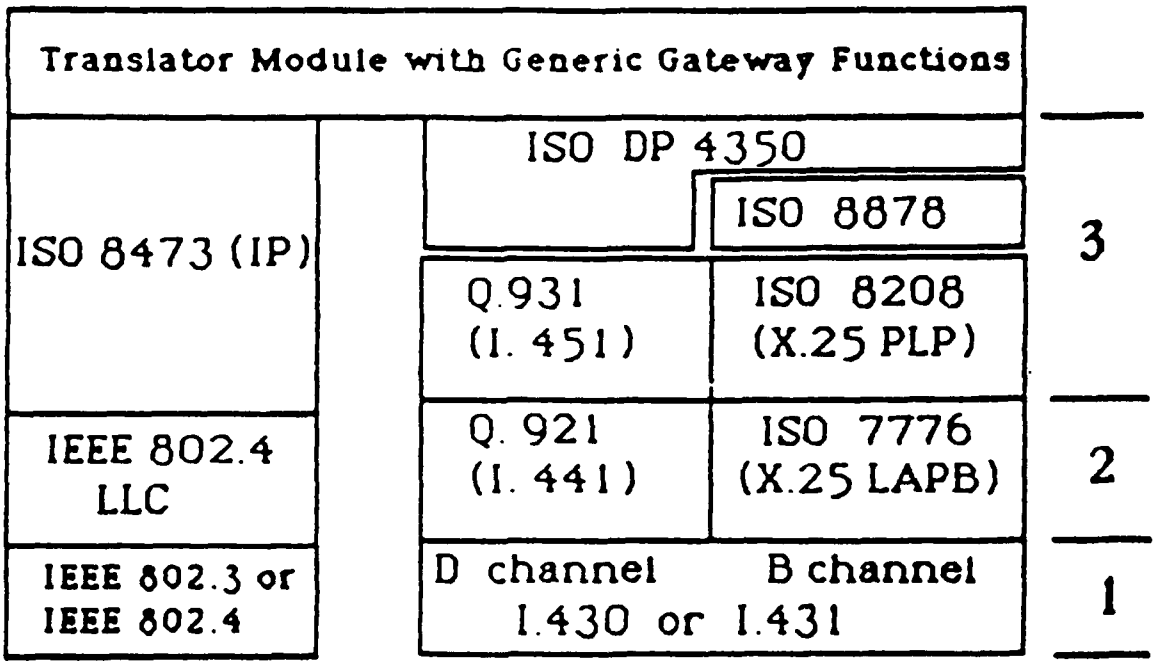


Fig. 5.34. The Layer Structure of Layer 3 ISDN-LAN (TOP or MAP) Gateway

Availability of ISDN chips[1]

Company	Product	Function
Siemens AG, Munich, West Germany	PEB2080 S-bus interface	Basic-rate interface Layer 1 functions for terminal and PBX application, including transceiver, activation-deactivation, collision resolution
	PEB2070 ISDN communication controller	D channel link access functions
	PEB2085 ISDN subscriber access controller	Combination of above two chips
	PEB2090 ISDN echo-cancelation circuit	Basic-rate U interface Layer 1 functions with 4B/3T block line code[3] and echo cancellation
Advanced Micro Devices Inc.,[2] Sunnyvale, Calif.	Am79c30 digital subscriber controller	Basic-rate interface functions including bus transceiver, D channel HDLC[4] function, collision resolution, audio processor for ISDN terminal
	Am79c32 data controller	Stripped-down version of Am79c30 without audio functions
	Am79c31 digital exchange controller	Basic-rate interface functions for PBX line cards, with transceiver, D-channel controller (HDLC), pulse-code modulation highway to pass B and D channels from multiple Am79c31 for centralized handling.
	Am79c33 transceiver echo canceller	Basic-rate U interface with echo cancellation and biphase line code
Mitel Inc., Kanata, Ont., Canada	MT8930 subscriber network interface circuit	Basic-rate interface including activation/deactivation, collision resolution, D-channel HDLC functions
	MT8972 digital network interface circuit	Basic-rate U interface with echo cancellation and biphase line code
Motorola Semiconductor, Austin, Texas	MC145474 S/T transceiver	Basic-rate Layer 1 interface, including transceiver, collision resolution, activation-deactivation for PBX and terminal application
	MC145472 U transceiver	Basic-rate U transceiver
Intel Corp., Santa Clara, Calif.	29c53 digital loop controller	Basic-rate interface function, including transceiver, HDLC function for D channel, use in terminals and PBXs
AT&T, Allentown, Pa.	T7250A user-network interface for terminal equipment	Basic-rate interface for terminals, including activation-deactivation, collision resolution, D-channel HDLC formatter, processor interface, timer
	T7260, T7261 U interface basic access transceiver	Basic-rate U interface devices with echo cancellation and AMI line coding[3]

1) As known by the author at the time of writing; may be incomplete

2) Advanced Micro Devices also has Am7936 and Am7938 chips to transfer power from the exchange and provide 6 volts to terminals

3) 4B/3T block line code and AMI (alternate mark inversion) are coding schemes for physically sending data on the line (OSI Level 1), neither of which conforms to the coding scheme standardized for the U interface by the T1D1 committee of the United States

4) HDLC (high-level data link control) is a method of grouping and formatting frames of data on the line (OSI Level 2)

Fig. 5.35. The Available ISDN VLSI Chips from Several Companies

5.8. Step 5: Decide What Kind of Chassis or Computer to Build the Gateway With

Based on "Figure 5.2: the DoD DCA proposed mid-term ISDN CONUS Architecture [25]," the LANs will connect ISDN-compatible PABX to access ISDN. So the chassis used for this ISDN-LAN gateway design could be the specific bus of the PABX. That is, this ISDN-LAN gateway design could be one or more boards which will be plugged into the specific bus of the ISDN-Compatible PABX (Private Automatic Branch Exchange). Figure 5.36 shows the scenario of ISDN-LAN gateway design using the specific bus of the ISDN-compatible PABX.

We can also choose a computer with two communication adapter boards to build the ISDN-LAN (TOP or MAP) gateway. One communication adapter board is for ISDN interface, the other is for LAN (TOP or MAP) interface. Considering the budget and the availability of communication adapter boards for ISDN, TOP, or MAP, the IBM-PC-386 compatible computers will be good candidates. Figure 5.37 shows the scenario of ISDN-LAN (TOP or MAP) gateway design using IBM-PC-386 compatible computer.

The reasons of choosing the IBM-PC-386 compatible computers for this ISDN-LAN (TOP or MAP) gateway design are:

1. The IBM-PC is the de-facto personal computer industry standard. There will be more software and hardware, especially communication adapter boards for ISDN, TOP, or MAP available at reasonable prices for IBM-PC series than those for other computers.

2. The IBM-PC-386 compatible computers use Intel 80386 CPU which has enough processing capability at reasonable price for gateway multi-tasking environment.

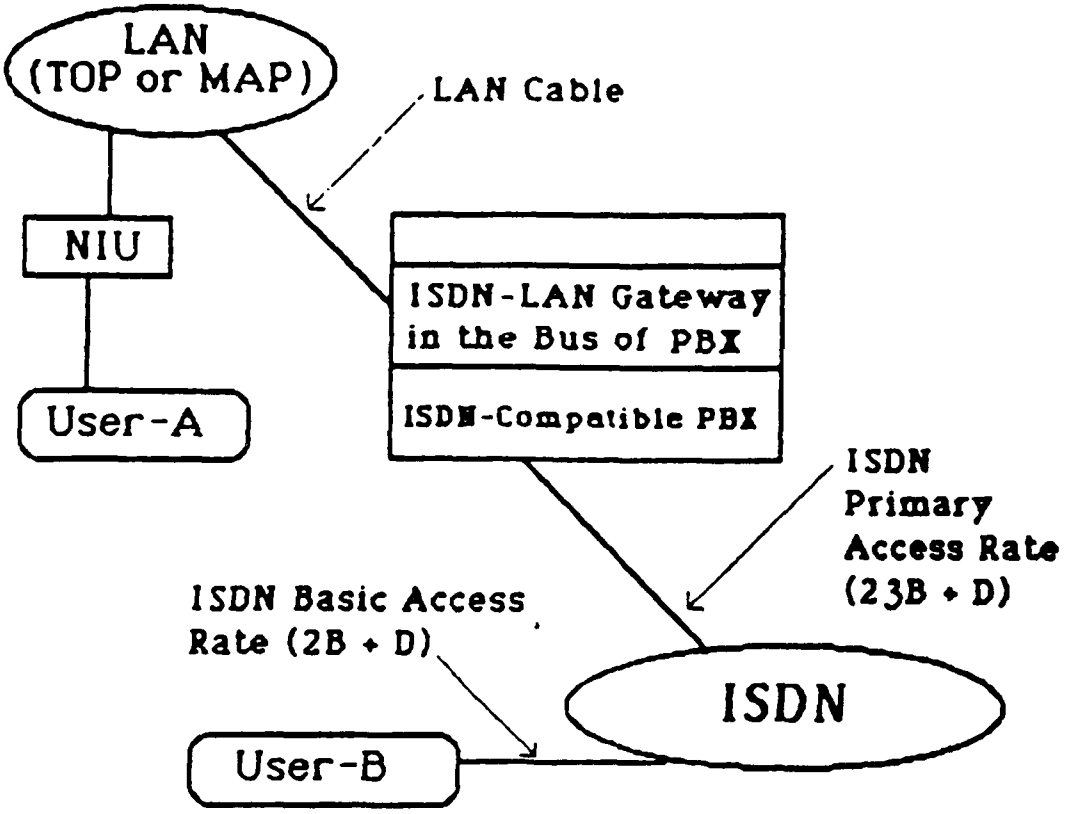


Fig. 5.36. The Scenario of ISDN-LAN (TOP or MAP) Gateway Design Using the Specific Bus of ISDN-Compatible PBX

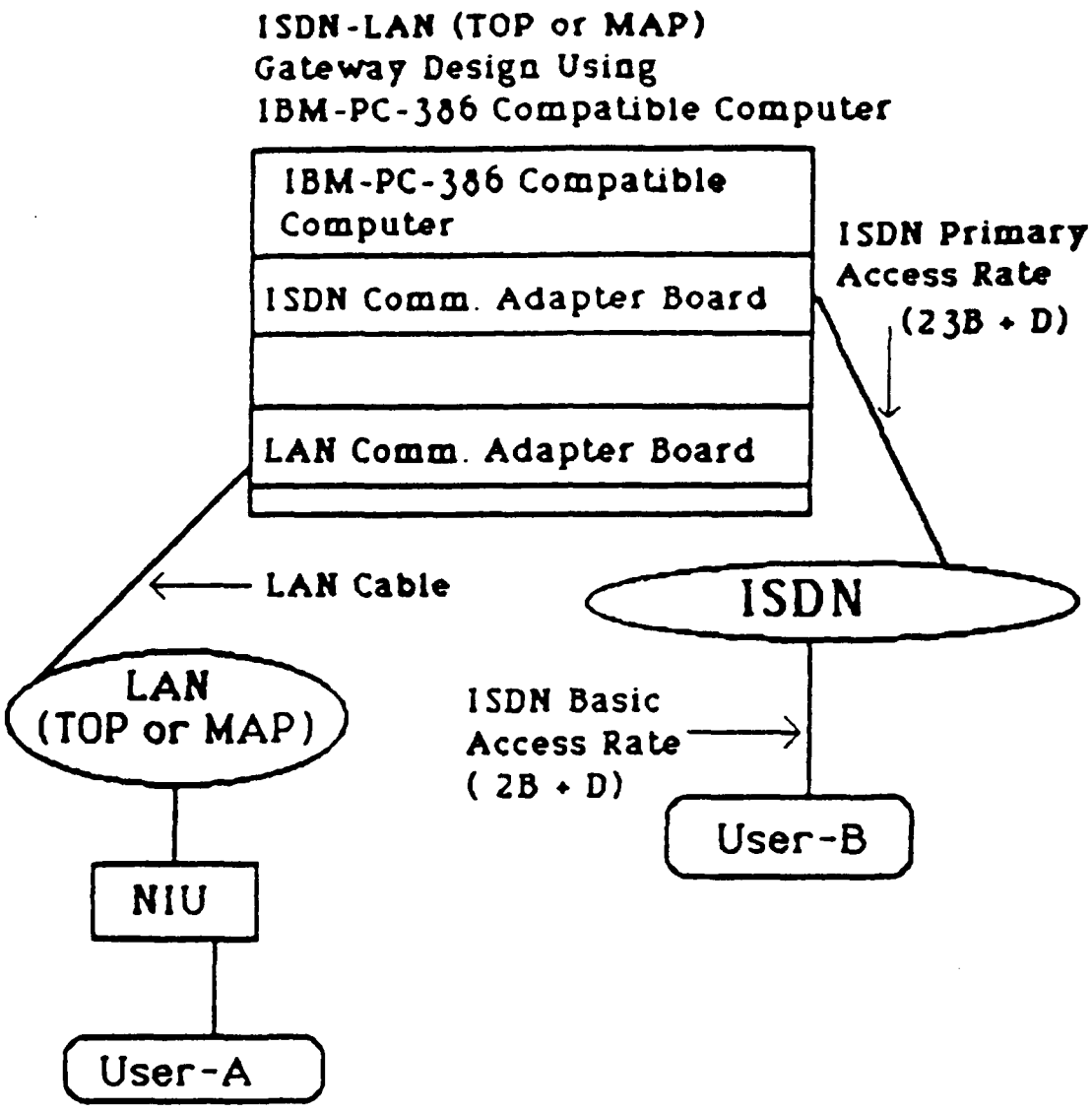


Fig. 5.37. The Scenario of ISDN-LAN (TOP or MAP) Gateway Design Using IBM-PC-386 Compatible Computer

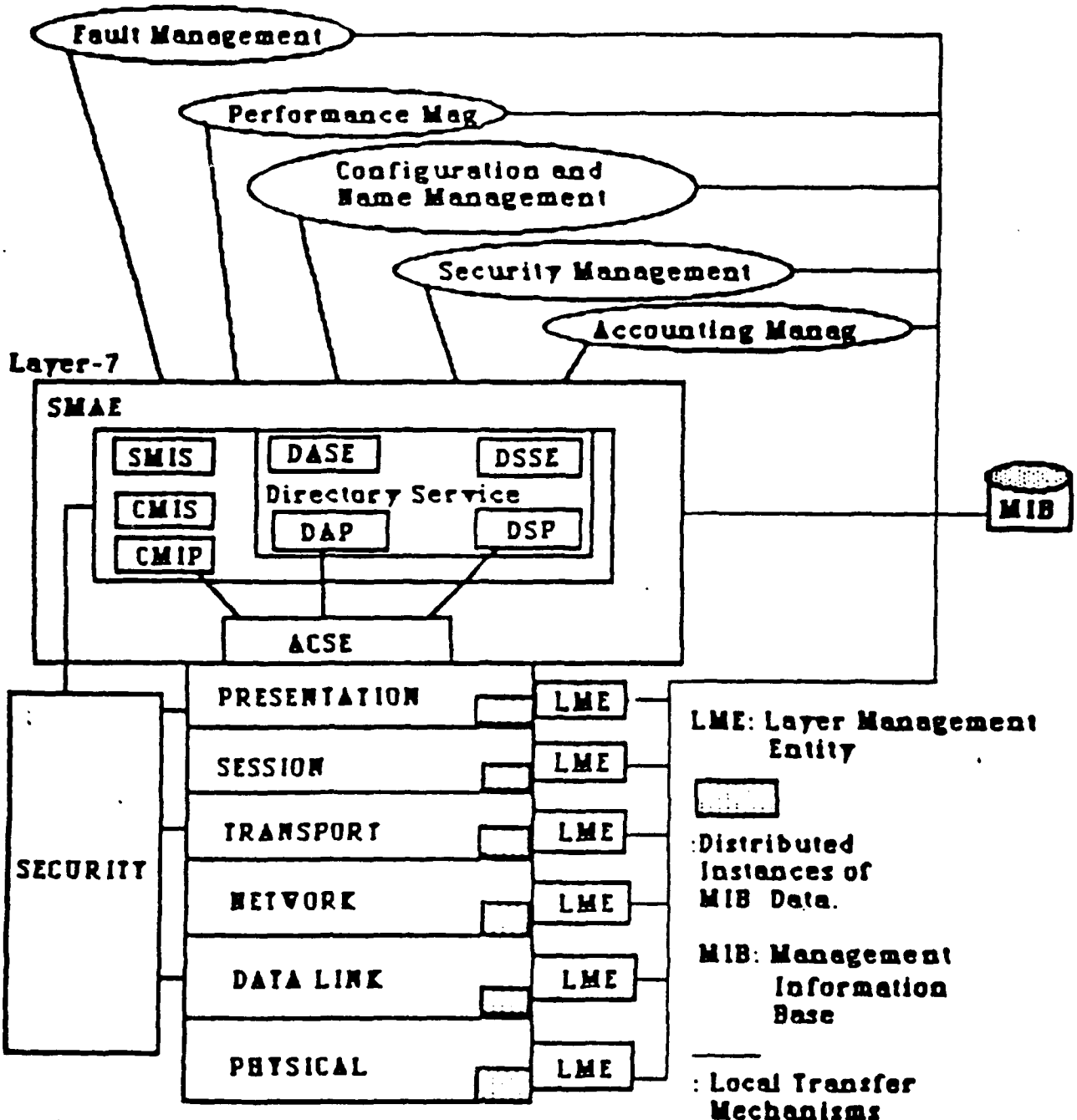
5.9. Step 6: Design the Translator Module to Interface with the Two Half-Gateway Modules

In Figures 4.1, 4.2, and 4.8, the generic gateway model consists of two half-gateway modules and one translator module. The generic gateway functions described in Section 4.2 are:

1. The Hardware and Software Functions of Network-A and Network-B. That is, the functions of the two Half-Gateway Modules.
2. Addressing, Naming, and Routing Functions.
3. Packet Fragmentation and Reassembly Functions.
4. Buffering and Flow Control Functions.
5. Congestion Control and Error Handling Functions.
6. Access and Security Control Functions.
7. Billing and Charging Functions.
8. Monitoring and Statistical Functions.
9. Management and Reconfiguration Functions.
10. Protocol Conversion Functions.

The generic gateway functions from 2 to 10 will be implemented in the translator module. Because the ISDN, TOP, and MAP are standard protocols, the implementation of these generic gateway functions will be a little easier. However, the detailed of the implementations of each of the generic gateway functions should be based on the characteristics of the ISDN, TOP, or MAP. The real implementation of the translator module of the ISDN-LAN (TOP or MAP) gateway needs further study. The ISO Internet Protocol (IP) is used by TOP and MAP. The ISO IP provides several features of internetworking requirements, and they will ease the implementation of generic gateway functions.

Several of the generic gateway functions are related to the network management functions. Figure 5.38 shows the network management concepts in the OSI environment. Figure 5.39 shows the concept of manager-agent protocol and the external view of network management architecture [37]. These network management concepts, such as manager-agent protocol, fault management, performance management, configuration and name management, security management, accounting management, layer management entity, distributed management information base, and so on, can be extended to apply to the internetworking environments. The extension of network management concepts to the implementation of generic gateway functions needs further study.



ACSE: Application Common Service Element
CMIP: Common Management Information Protocol
CMIS: Common Management Information Service
DAP: Directory Access Protocol
DASE: Directory Access Service Element
DSP: Directory System Protocol
DSSE: Directory System Service Element
LME: Layer Management Entity
MIB: Management Information Base
SMAE: System Management Application Entity
SMIS: Specific Management Information-Passing Service

Fig. 5.38. The Network Management Concept in the OSI Environment

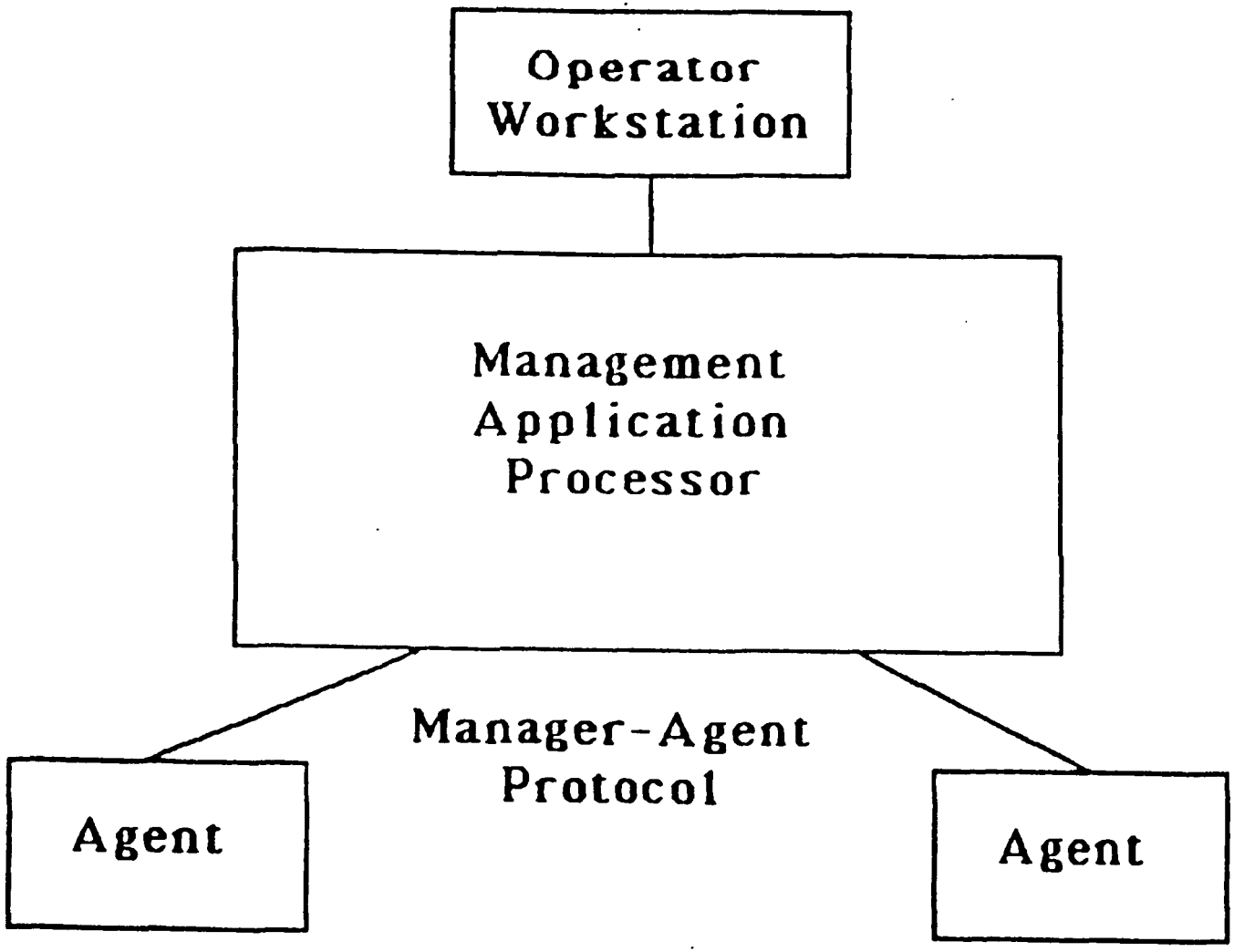


Fig. 5.39. The Concept of Manager-Agent Protocol and the External View of the Network Management Architecture

5.10. Step 7: Implement and Test the Integrated Gateway

As we mentioned in Section 4.3.3.7 the implementation and testing philosophy of an integrated gateway is as follows:

1. During the integrated gateway designing process, how to test each of the implementation stages and the final product should always be kept in mind.
2. The implementation and testing should start from basic to advanced, from simple to complex.

Based on the philosophy above, the ISDN-LAN (TOP or MAP) gateway implementation and testing procedures are as follows:

1. Implement and test each of the two half-gateway modules (A&B). First, test the Half-Gateway-Module-A which connects and interfaces with the LAN (TOP or MAP). Make sure all the hardware and software in the Half-Gateway-Module-A work properly and can communicate with the LAN (TOP or MAP). Then, test the Half-Gateway-Module-B which connects and interfaces with ISDN. Make sure all the hardware and software in the Half-Gateway-Module-B work properly and can communicate with ISDN.
2. Implement and test the simplified version of the translator module. That is, just put the service mapping or protocol conversion function (sometimes manually) in the translator module. Make sure the simplified translator module can interface with the two half-gateway-modules (A&B).
3. Add the generic gateway functions mentioned in Section 4.2 and Section 5.9 to the translator module, one function at a time. Make sure the function just added works properly, then add next function and test it. Most of the implementations of the

generic gateway functions are software-dependent. Based on the characteristics of ISDN and LAN (TOP or MAP), each of the generic gateway functions should be implemented and tested one by one before all functions being integrated together.

4. The final testing of the completed ISDN-LAN (TOP or MAP) integrated gateway should be tested on the end-system-to-end-system basis. We mentioned that the integrated gateway design should consider the compatibility of the upper layer protocol in the end-systems. In this ISDN-LAN (TOP or MAP) gateway design, we assume the upper four layers in the end-systems are compatible. The final testing should test this assumption is true or not. The LAN provides the data service to end-systems connected to LAN, and the ISDN provides the data, voice, image services to end-systems connected to ISDN. Because no digital telephones are connected to LAN, and the services provided by ISDN and that of LAN are not the same, the ISDN-LAN (TOP or MAP) gateway can be used for data service between ISDN and LAN only.

We emphasize here again that because the ISDN, TOP, and MAP are standard protocols, the off-the-shelf software and hardware products will make this ISDN-LAN (TOP or MAP) gateway design a little easier. The off-the-shelf VLSI chips and communication adapter boards for ISDN, TOP, or MAP can be used in this ISDN-LAN gateway. However, caution must be taken to handle the parameters and options used by each ISDN, TOP, or MAP products. Otherwise, as the example of X.25 protocol implementations mentioned in Section 5.1 (Figure 5.2), the use of the same set of protocols cannot guarantee the compatibility of two products or two

networks. We can and should use the off-the-shelf products for ISDN, TOP, or MAP for this ISDN-LAN (TOP or MAP) gateway design. However, the final testing is the only way to quarantee the proper use of the off-the-shelf products and successfully internetworking ISDN with TOP or MAP by the ISDN-LAN (TOP or MAP) gateway.

6.0 INTRODUCTION: INTERNTEWORKING DDN AND ISDN

The approach to internetworking the Defense Data Network (DDN) and the Integrated Services Digital Network (ISDN) is to design and build an integrated gateway. The general approach to this internetworking problem was presented in Section 4.3.3 of this report, Approach 3: Integrated Gateway. In this section the general approach will be applied to the specific case of internetworking DDN and ISDN.

The value of internetworking DDN and ISDN is manifested by the many ways that ISDN services will enhance the DDN. In addition to the wide range of services provided by ISDN, perhaps the most significant benefit from internetworking DDN and ISDN is the reduction of future internetworking problems. Part of the intention behind the development of an ISDN is to create an international standard that will endure the test of time and adapt to changing technology. As ISDN matures, more and more networks will have gateways that access ISDN. This will provide the DDN with avenues to communicate with other networks that are linked to ISDN. In this respect, ISDN can be regarded as a neutral network providing the link between two end networks. Figure 6.1 shows the scenario of internetworking DDN with three other networks using ISDN as a neutral network. Figure 6.2 shows the alternate scenario without ISDN. One can imagine the complexity of this alternate internetworking method as the number of networks is increased. When using ISDN as a neutral network, only one gateway is required per network. The DDN/ISDN internetworking problem is of special interest because of the

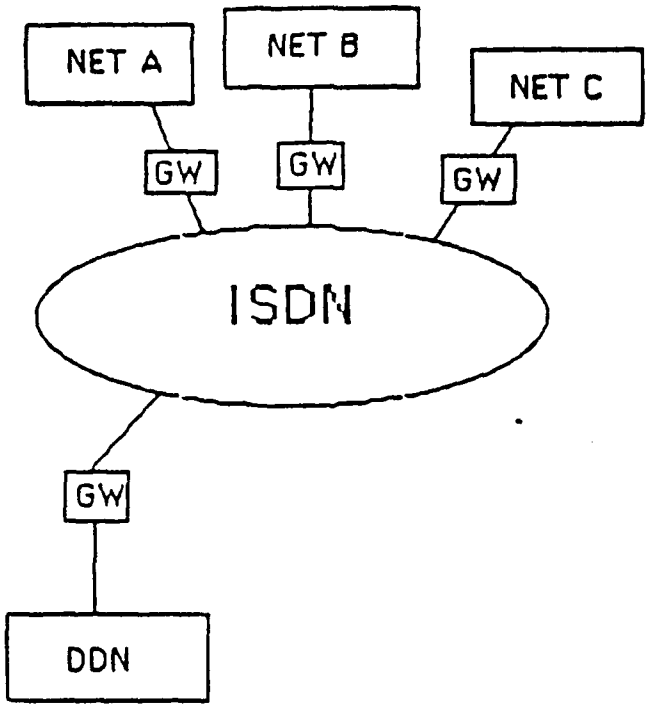


Fig. 6.1 Internetworking DDN with three networks using four gateways and ISDN as a neutral network

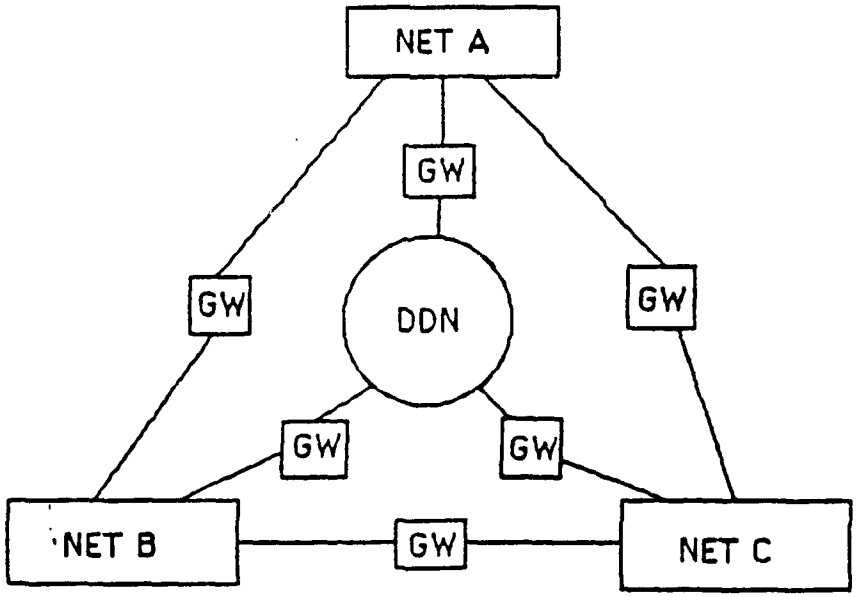


Fig. 6.2 Internetworking DDN with three networks using six gateways

wide spread use of the DoD Internet Protocols. Many other networks will use gateways that closely resemble the DDN/ISDN gateway to solve their ISDN internetworking problems.

6.1 Step 1: Understand the Characteristics of ISDN and DDN

The first step in designing an integrated gateway is to use the two networks and understand all aspects of their operation. This includes hardware, software, and protocols. The protocol structures of DDN and ISDN are shown in Figure 6.3 and Figure 6.4 respectively. DDN uses either the 1822 or the X.21 protocol at the physical layer, X.25 protocol at the data link layer, Internet Protocol (IP) at the network layer, and the Transmission Control Protocol (TCP) at the transport layer. For the scope of this report we will concern ourselves with the X.21 protocol at the physical layer. TCP and IP are often jointly referred to as "internet protocols." Because these internet protocols were developed before the OSI 7 layer model was adopted as a standard, there is not a direct mapping between the internet protocols and the seven layers of the OSI model. This will become more evident when the structure of the gateway is presented later in this report. The ISDN protocols shown in Figure 6.4 have been chosen to be compatible with the OSI 7 layer model. At the physical layer ISDN uses the protocol specified in the CCITT I-Series Recommendations I.430 and I.431. This protocol uses time division multiplexing to separate the B and D channels. This unique approach is an out-of-band signaling method, also called common-channel signaling. ISDN uses Signaling System #7 (SS7) on the D-channel for signaling information which keeps the B

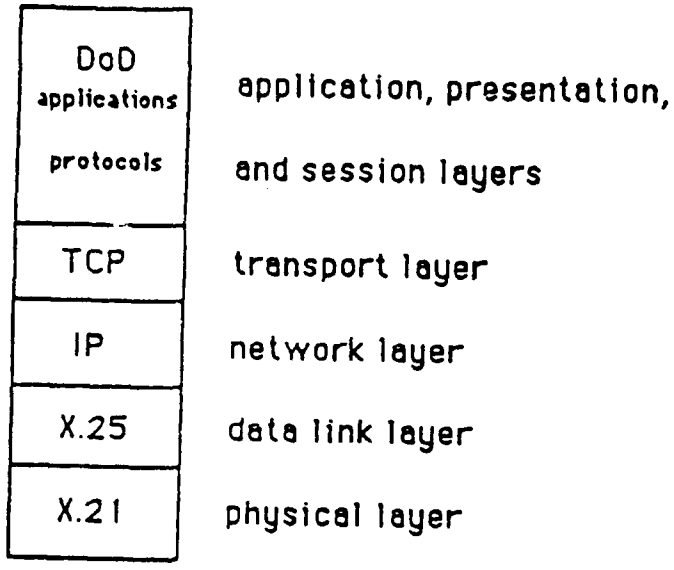


Fig. 6.3 DDN protocol structure implementing X.25

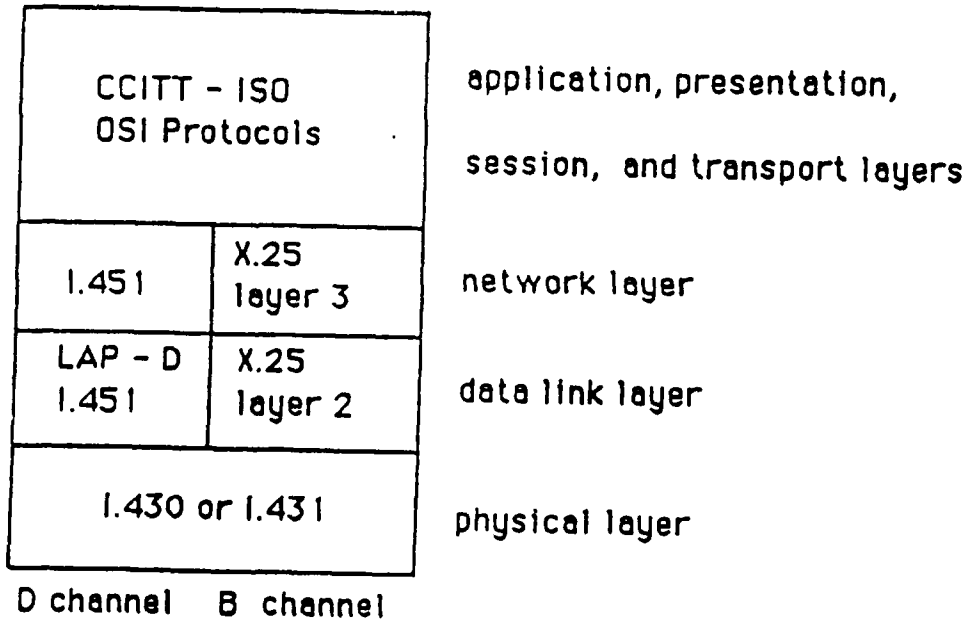
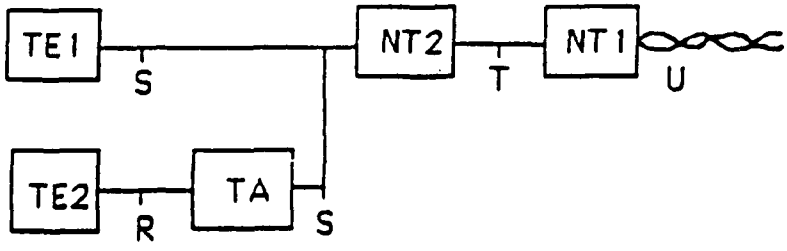


Fig. 6.4 ISDN protocol structure

channels open for the transmission of data without consuming any bits for connection control commands. Because the B and D channels have two very different functions, they both implement different protocols. The B-channel uses the LAP-B protocol which is a subset of X.25 at the data link layer, and the X.25 protocol standard at the network layer. The D-channel uses the LAP-D protocol at the data link layer, and the I-Series Recommendation I.451 protocol at the network layer. Because of their importance, I.451 and LAP-D are very complex protocols. If the D-channel fails, the entire network becomes useless. For this particular reason, CCITT devoted most of the earlier proceedings to defining the user-network interface. The ISDN user-network interface is shown in Figure 6.5. This diagram illustrates the R, S, T, and U, interface points, and the NT1, NT2, TE1, TE2, and TA functional blocks. The NT1, network termination type 1, performs the physical layer functions (receiving and transmitting bits). The NT2 performs the functions of the data link layer and network layer. TE1 and TE2 refer to terminal type 1 and terminal type 2. The difference between the two types of terminals is ISDN compatibility. A type 2 terminal is not ISDN-compatible and therefore requires a terminal adapter, TA. The DDN is not compatible with ISDN, and because of this an integrated gateway must be designed and built. The gateway will perform the functions of the NT1, NT2, and TA all within one chassis. The approach to implementing these gateway functions is presented in Section 6.4 and Section 6.6.



NT1 - Network Termination type 1
NT2 - Network Termination type 2
TE1 - Terminal type 1 (ISDN)
TA - Terminal Adapter
TE2 - Terminal type 2 (non-ISDN)

Fig. 6.5 ISDN user-network interface.

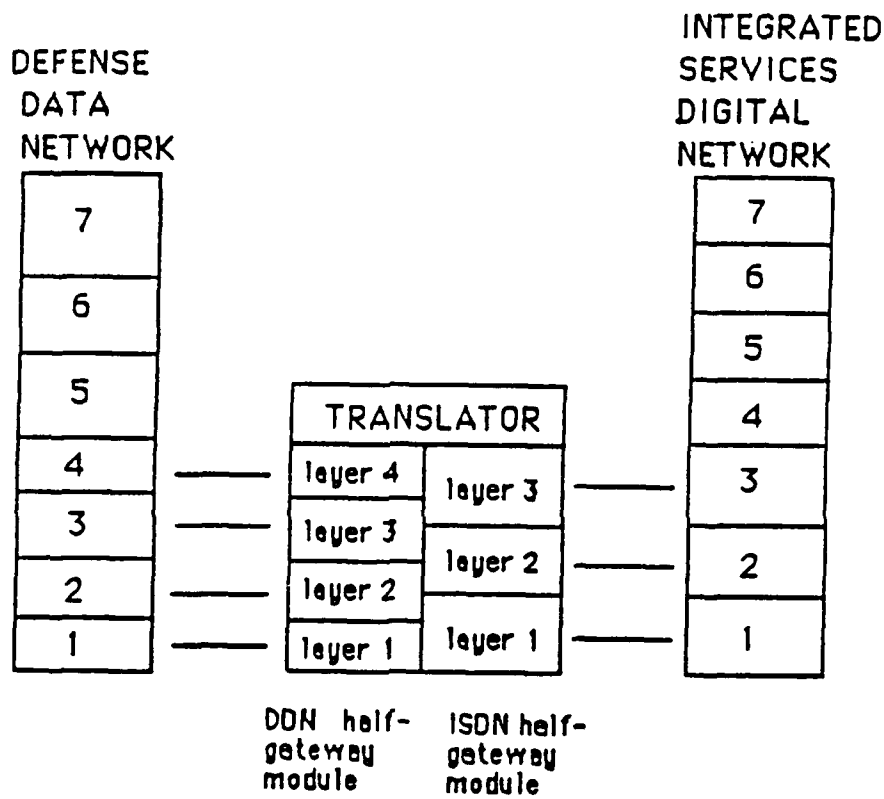


Fig. 6.6 DDN/ISDN gateway configuration.

protocols that exist in the DoD Internet Protocol Suite, an assumption must be made that the two end systems are compatible at the upper layers. Figure 6.7 depicts this end-to-end peer layer compatibility. An example of an applications protocol is electronic mail. The electronic mail facility within the DDN is supported by the Simple Mail Transfer Protocol (SMTP) which is built upon the services provided by TCP. The two end systems must both use the SMTP or a compatible protocol in order to be certain that no mismatches occur. A logical solution would be to build a 7 layer gateway to alleviate the concern for compatibility at the upper layers, but because there are so many applications protocols in the internet environment it would be virtually impossible to build a gateway that could handle such a wide range of protocols effectively. Instead, we must make the assumption that the upper layers are compatible in the two end systems.

6.4 Step 4: Obtain the Required Information About DDN and ISDN

The information needed for the internal design of the DDN/ISDN gateway is relatively easy to obtain. Both DDN and ISDN are very common networks whose structures are both looked upon as standards. A complete description of ISDN standards is available in CCITT's Red Book, I-Series Recommendations. The required information about the DDN can be found in a variety of DoD RFC's. These RFC's will be mentioned later in this section. This section will explain in moderate detail the functions of the DDN and ISDN half-gateway modules and provide the information needed

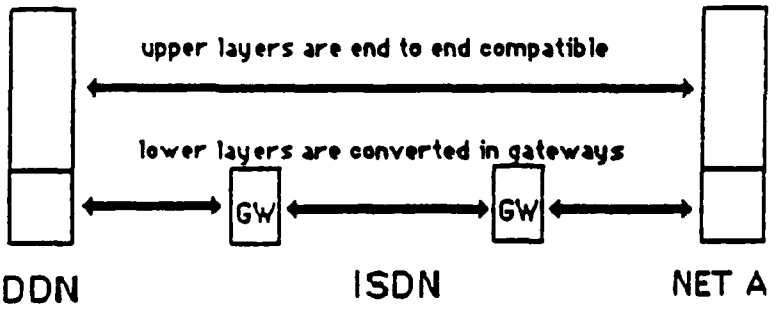


Fig. 6.7 Gateway configuration showing end to end compatibility of upper layers for applications protocols.

to implement these functions or direct the reader to the appropriate source to obtain this information.

6.4.1 ISDN half-gateway module

The ISDN half-gateway module consists of 3 layers, physical layer, data link layer, and network layer. Figure 6.8 shows the functional decomposition of the ISDN half-gateway module by layers. There are some interesting things to note about this diagram. The most significant point is the separation of the B and D channels at the physical layer. This allows signaling information to be transmitted separately from the data. Another important characteristic is the multiplexing performed at layers 2 and 3. Multiplexing is used to support multiple service access points and to increase throughput. The following sections explain the functions of each layer and the protocols used for both the B and D channels.

6.4.1.1 ISDN Physical Layer

The physical layer of the ISDN user-network interface is specified in CCITT's Recommendation I.430 for the basic rate subscriber and Recommendation I.431 for the primary rate subscriber. The layer 1 characteristics defined by these recommendations are to be applied at the S and T reference points of the ISDN user-network interface shown in Figure 6.5. The main services provided at the physical layer include:

1 Transmission and Reception of encoded bit streams of both B and D channels with the proper alignment,
2 Control of access to the common resource of the D-channel for signaling information,

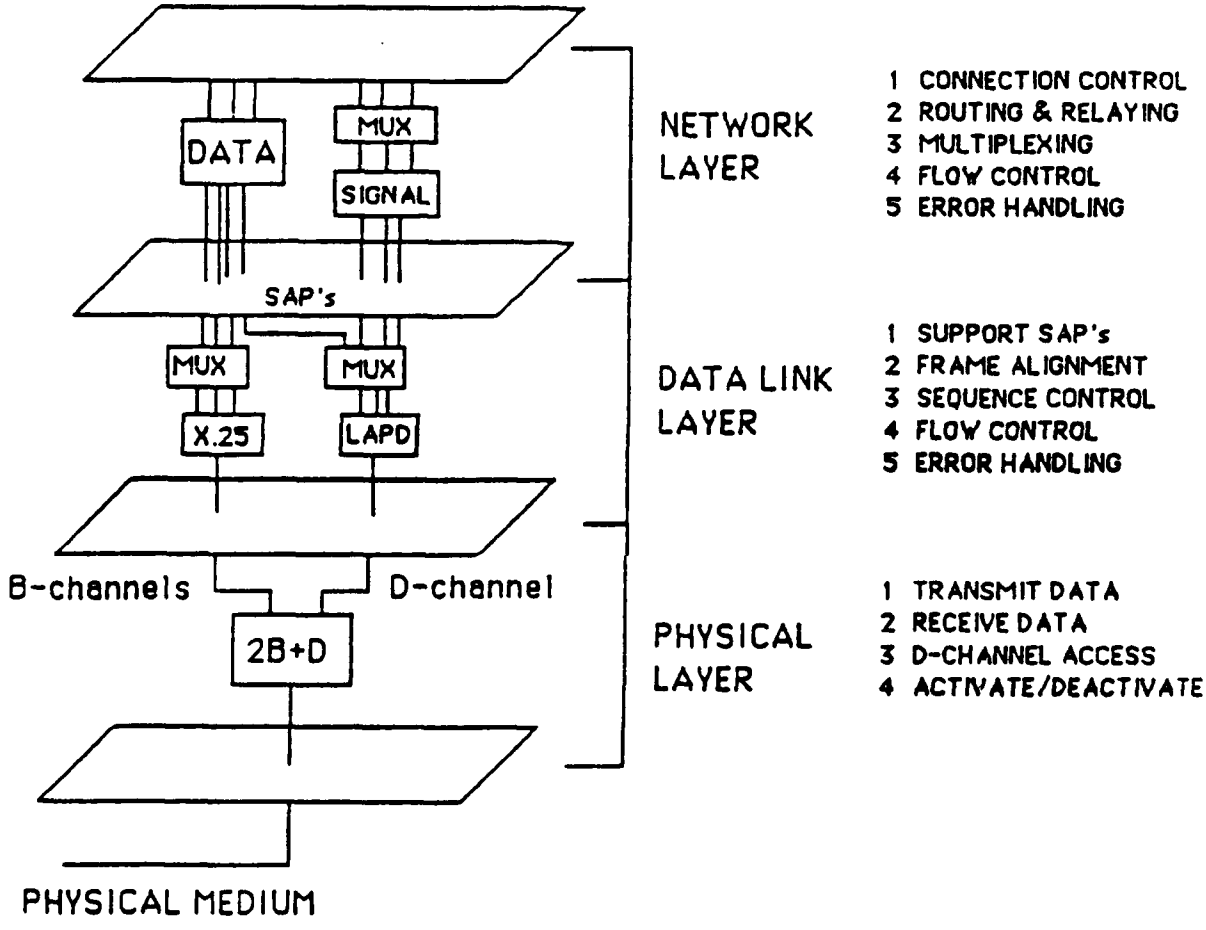


Fig. 6.8 Functional decomposition of the ISDN half gateway module

3 Activation and Deactivation of terminals.

Other services provided by the physical layer include maintenance functions, status indication to upper layers, and power feeding. The information on the physical medium is coded using a pseudo-ternary coding scheme. Figure 6.9 shows how this coding scheme is implemented. Binary ones are represented with no line signal, and binary zeroes are represented by alternating positive and negative pulses. The first binary zero takes the same polarity as the preceding framing balance bit. The bits within each frame are separated into three channels, 2B + D, using time division multiplexing. The layer 1 frame structure for the basic-rate interface is shown in Figure 6.10. The frame structure is dependent on the direction that the frame is being transmitted, whether it be TE to NT, or NT to TE. In either case each frame contains 48 bits which are transmitted in a time period of 250 microseconds. This corresponds to an aggregate data rate of 192 kilobits per second (Kbps). Frames being sent from TE to NT, outgoing frames, are offset by two bits from the incoming frames, NT to TE. Both types of frames contain 4 D-channel bits, 16 B1-channel bits, and 16 B2-channel bits. This makes the information rates 16 Kbps for the D-channel and 64 Kbps for both of the B channels. Each frame also contains framing bits and DC balance bits. The incoming frames also contain D-channel echo bits, and a terminal activation bit. The D-channel echo bit is set to the value of the D-channel bit on the previous outgoing frame as indicated by the diagram. This echo bit is monitored by terminals that wish to gain access to the D-channel. The

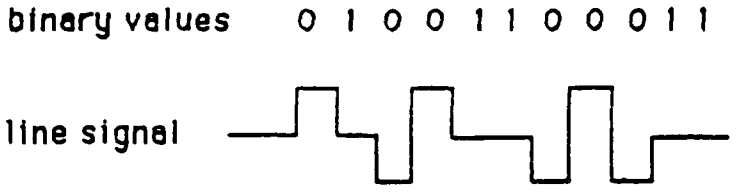


Fig. 6.9 Example of pseudo-ternary coding scheme used by ISDN's physical layer.

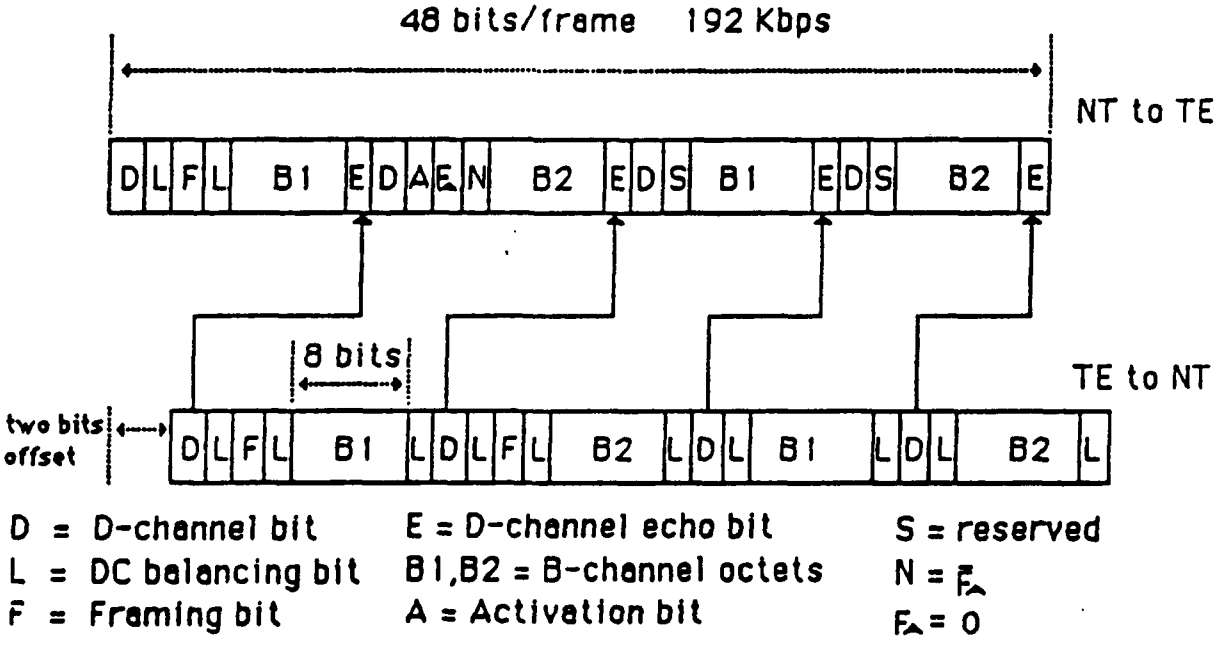


Fig. 6.10 Frame structure at the physical layer of the ISDN user-network interface for the basic rate subscriber.

physical layer entity is responsible for granting access to the D-channel. Recommendation I.430 describes how the physical layer handles prioritized information and collisions on the D-channel. Recommendation I.431 specifies the ISDN primary rate user-network interface. Frames for the primary rate interface are 193 bits in length and are transmitted in a time period of 125 microseconds. This makes the total data rate 1544 Kbps. Each frame is time division multiplexed into 23 B-channels at 64Kbps and one D-channel for signaling which is also 64 Kbps.

6.4.1.2 Data Link Layer for the D-channel

As mentioned earlier, the B and D channels implement two different protocols at the data link layer of the ISDN user-network interface. The D-channel uses the protocol specified by CCITT's Recommendation I.441 (LAP-D), and the B-channel uses the X.25 (LAP-B) protocol. Although most issues about these protocols have been resolved and they are considered as standards, there are some functions and services which are still undefined and currently being studied by CCITT.

CCITT has specified LAP-D as the protocol for the D-channel at the data link layer. The data link layer is responsible for many of the critical functions to be performed by the integrated gateway between DDN and ISDN. Some of these layer 2 functions are listed below:

1 support of multiple service access points (SAP) to the network layer,

2 frame alignment,

3 sequence control,

4 error detection and recovery,

5 flow control.

The procedure taken by the LAP-D protocol is to accept the D-channel bits from the physical layer and to align the frames by detecting the flag bit sequences, {01111110}, which are placed at the front and end of every frame. Figure 6.11 shows the frame structure of the LAP-D protocol. After aligning the frame the layer 2 entity computes a frame check sequence (FCS) and compares it with the FCS field. If the values are not equal the frame is rejected and the data link layer will send a reject command to request retransmission of the frame. If the frame is received correctly, (computed FCS = transmitted FCS), the data link layer then analyzes the address field. The format of the address field is shown in Figure 6.12. The two main fields within the address are the Service Access Point Identifier (SAPI), and the Terminal Endpoint Identifier (TEI). The SAPI identifies the point where the frame is delivered to the network layer entity to process the information contained in the frame. The TEI identifies a single terminal and has a range of 0 to 127. The value 127 is reserved for broadcast information. The TEI can be a number which is assigned at the time of call connection or can be a number which is permanently given to the terminal. Figure 6.13 illustrates the difference between the SAPI and the TEI. In this figure SAPI = 16 indicates that the frame contains packetized data, and SAPI = 0 indicates that the frame contains signaling information. Within each service access point there may be up to 127 different terminal endpoints. The control field of the LAP-D protocol may

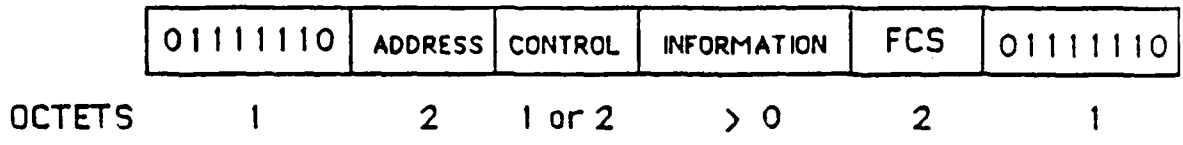
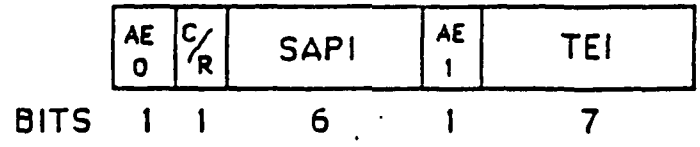
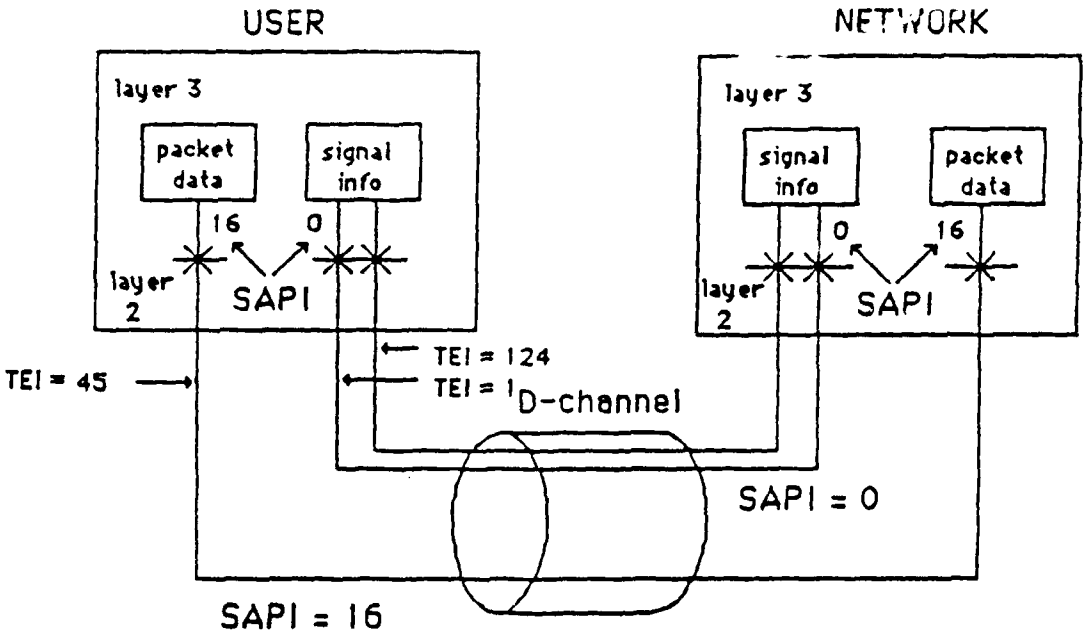


Fig. 6.11 Frame structure of the LAP-D protocol.



AE = Address Extension Bit
C/R = Command/Response Bit
SAPI = Service Access Point Identifier
TEI = Terminal Endpoint Identifier

Fig. 6.12 LAP-D address field format.



SAPI = Service Access Point Identifier
TEI = Terminal Endpoint Identifier

Fig. 6.13 Example of D-channel data-link showing distinction between SAPI and TEI at the layer 3 interface.

be one or two octets in length and is used to identify commands and responses. There are three types of control field formats, Information (I) frames, Supervisory (S) frames, and Unnumbered Information (U) frames. These formats are shown in Figure 6.14. I frames are used to transmit information between layer three entities. I frames contain sequence numbers, N(s) and N(r), which are used to reorganize packets that may have gotten out of order during transmission. U frames are used to transmit unacknowledged information. S frames are used by the data link layer to perform supervisory control functions. An example would be requesting retransmission of an I frame that had an error. The supervisory control frames are also used to implement the flow control services provided by the data link layer.

6.4.1.3 Network Layer for ISDN's D-channel

The functions and protocol employed at the network layer, layer 3, of the ISDN user-network interface are described in CCITT's Recommendation I.451. The D-channel network layer protocol is a very complex protocol, and carries a great deal of responsibility within the structure of the ISDN user-network interface. Some of the duties of the D-channel network layer are listed below:

1 network connection control,

2 routing and relaying,

3 multiplexing and rate adaption,

4 flow control and sequencing,

5 error detection and recovery.

CONTROL FIELD FORMAT	8	7	6	5	4	3	2	1
INFORMATION (I)	N(R)			P	N(S)			0
SUPERVISORY (S)	N(R)			P/F	S	S	0	1
UNNUMBERED INFORMATION (U)	M	M	M	P/F	M	M	1	1

N(S) Transmitter send sequence number
N(R) Transmitter receive sequence number
S Supervisory Function bits
M Modifier Function bits
P/F Poll = command, Final = response

Fig. 6.14 Control field format of the LAP-D protocol.

The network layer receives assistance in implementing these functions by using primitives to communicate with the data link layer. The network layer also generates and interprets layer 3 messages for peer-level communication between the two end systems. The messages sent between the peer-level network layers and between the network and data link layers are always transparent to the user. A complex set of network layer primitives are used to control network connections. The procedure for interpreting layer 3 messages to extract these primitives will be explained later in this section. The routing and relaying functions provided by the network layer are used to determine the appropriate route to direct information between layer 3 addresses. Multiplexing and rate adaption are very important functions provided by the network layer to improve the efficiency of packet-switched information flow on the B and D channels. Flow control is achieved with the help of the data link layer primitives which communicate Receive_Ready and Receive_Not_Ready indications to the network layer and vice versa. Sequencing is used to ensure that data is reconstructed in the same order that it was submitted by the user. Error handling functions are also completed with the assistance of the data link layer. The data link layer is responsible for detecting errors that occur during transmission, while the network layer is responsible for detecting and recovering from procedural errors. Network messages are contained in the data link layer information field, and are passed to the network layer via service access points. Network layer messages have the

format shown in Figure 6.15. After the network layer accepts a message form the data link layer, it reads the protocol discriminator. The protocol discriminator identifies the general type of message whether it be for call control or some other type of layer 3 function. A complete list of protocol discriminator values can be found in the I-Series Recommendation I.451. The call reference value field is used to identify the call or facility at the user-network interface to which the message applies. The message type is analyzed to indicate the function of the message. These functions are actually network layer service primitives. This one octet of information is the heart and soul of the network connection control. The eighth bit of this octet is reserved for extension purposes. Additional information is appended to the end of the message. This additional information is usually specific to the type of message that was sent. For some types of messages no additional information is needed and therefore this field is optional. In the event that additional information is appended to the message, the first octet identifies the type of information and the second octet specifies the length of the information field. Examples of additional information are channel identification and connected address identification. Channel identification is very important when sub-channels are multiplexed into the same B-channel. When several sub-channels of lower data rates are requesting use of the B-channels, the network layer multiplexes them into the same channel by assigning slot numbers (slots of time) to the channels. The format of the channel identification information

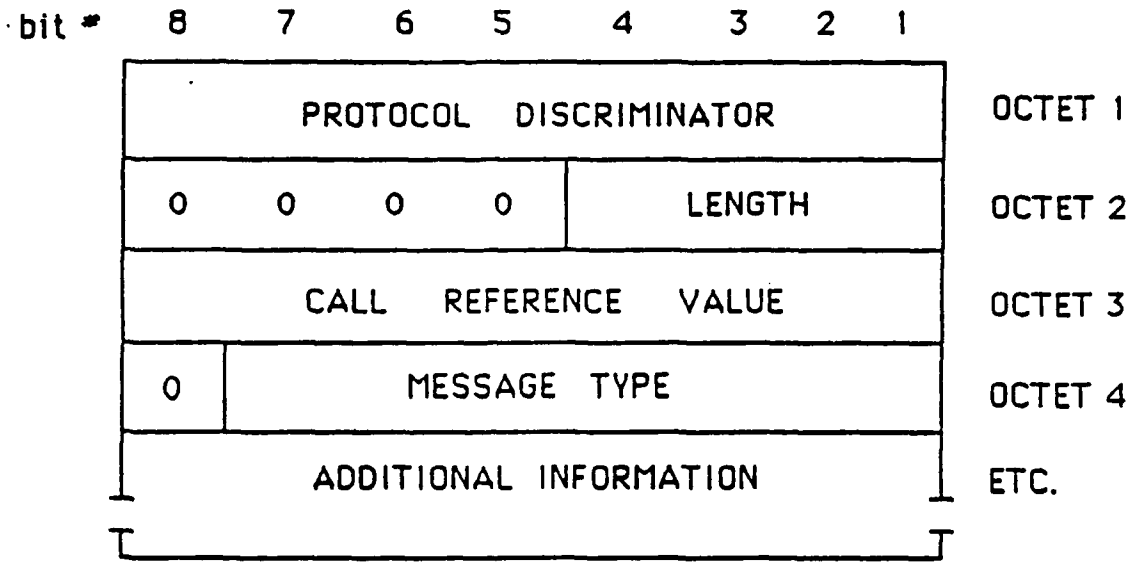


Fig. 6.15 Structure of layer 3 message on ISDN's D-channel.

element is shown in Figure 6.16. The first octet is the information element identifier. In Figure 6.16 the number {00011000} signifies channel identification. The second octet tells how long the field is, and the third octet is used to specify the type of interface (basic or primary) and channel type (B1, B2, or D). The interface identifier is a binary number that is assigned to the interface at the time of subscription. The next two octets identify the coding standard and the mapping information used to multiplex the channels. These two octets can be repeated to signify further sub-channeling. For the primary-rate interface the format for channel identification is slightly different in order to be able to differentiate between 23 B channels. The format for connected address information is shown in Figure 6.17. The first two octets are identifier and length fields. The third octet contains address type and numbering plan fields. The address type specifies either international ISDN number, national ISDN number, ISDN sub-address, or some alternate type of address. The actual address then starts in the fourth octet.

6.4.1.4 Data Link Layer for ISDN's B-channel

The ISDN B-channel protocol is LAP-B which is a subset of X.25 and uses the standard High Level Data Link Control (HDLC) frame structure. X.25 is noticeably different from the LAP-D protocol that is used on ISDN's D-channel. This difference in protocol seems only practical when the dissimilarity in function of the two channels is considered. The B channels are used to transmit 64 Kbps data, and the D-channel transports signaling

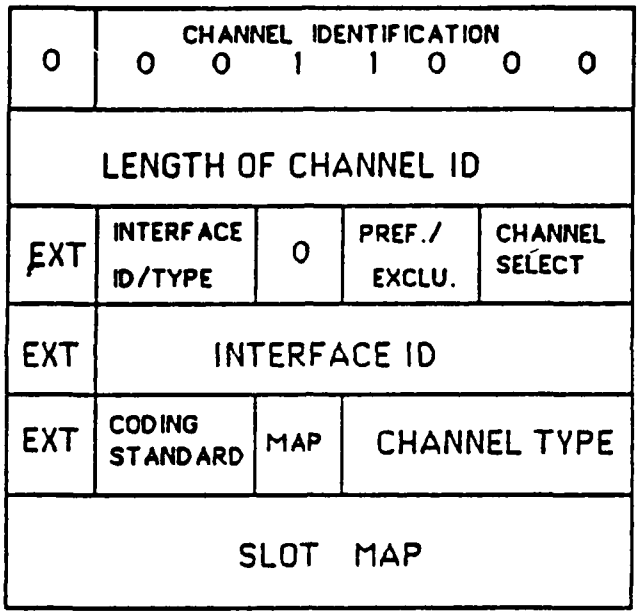


Fig. 6.16 Channel identification information element structure appended to an ISDN layer 3 message

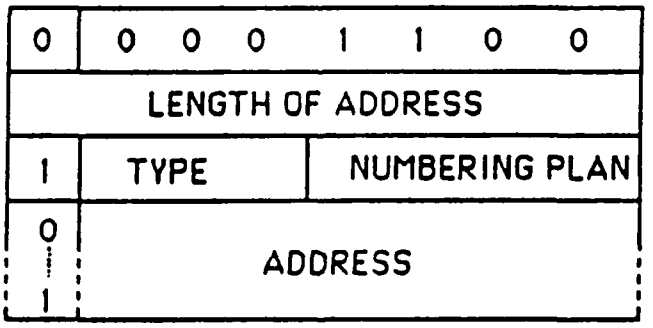


Fig. 6.17 Connected address information element structure appended to an ISDN layer 3 message

information and low speed packet data. Despite this difference the functions of the two protocols are very similar. This is due to OSI standardization. The functions of X.25 are listed below:

1 support multiple Service Access Points,

2 frame alignment,

3 error detection and recovery,

4 flow control,

5 sequencing.

The standard HDLC frame structure is shown in Figure 6.18. The data link layer aligns the frames by synchronizing with the header and trailer flags. Bit-stuffing is used to prevent the flag pattern from appearing inside the frame. The frame check sequence (FCS) is computed and compared against the number in the FCS field. If an error is detected, the data link layer will request that the frame be retransmitted. The address field is normally 8 bits long, but can be extended in incremental numbers of octets. The eighth bit is used as the extension bit. A one in this bit position indicates the end of the address field. All ones in the address field are used for broadcast information. This address should be able to identify multiple layer 3 service access points and multiple processes within these SAP's. The control field is used to identify the frame type either information, supervisory, or unnumbered information frames. The structure of the X.25 control field is the same as the control field for LAP-D. This field is shown in Figure 6.14. The information and supervisory frames contain sequence numbers which are used to keep data organized in the proper order, and are also

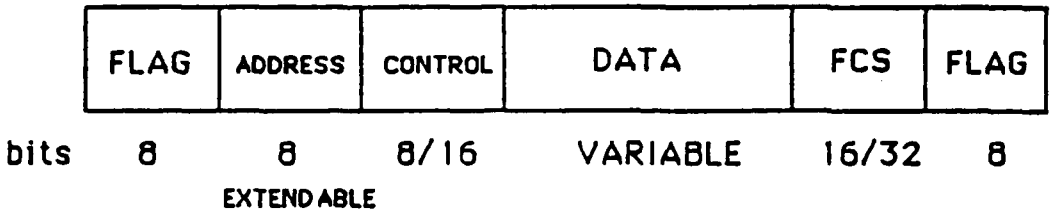


Fig. 6.18 X.25 protocol frame structure for the data link layer.

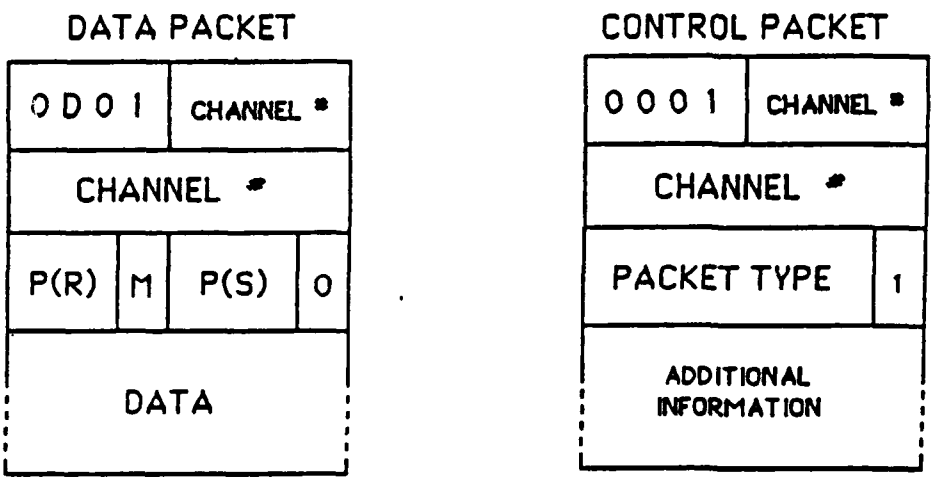


Fig. 6.19 Data and Control packets used at the network layer on ISDN's B-channel.

needed to implement flow control and error recovery functions. The flow control function is implemanted using a sliding window. This window will only accept frames with sequence numbers that are between the limits of the window. Sequence numbers can vary in length depending on the modulus being used either modulus 8 or modulus 128. The modulus is set by sending an S frame containing the proper set-mode command. When the modulus is set to 128 the control field is extended to 16 bits to accommodate the larger sequence numbers.

6.4.1.5 Network Layer for ISDN's B-channel

At the network layer ISDN's B-channel uses the X.25 layer 3 protocol standard. The functions performed at the network layer are listed below:

1 multiplexing,

2 flow control,

3 sequencing,

4 error handling.

The network layer protocol uses two types of packets, data packets and control packets. The format for these two packets are shown in Figure 6.19. Bit position one of the third octet is the delimiter that identifies the packet as either data or control. Both packet types contain a 12 bit channel identification field. This 12 bit identification will allow up to 4095 channels to be multiplexed through the network layer. The data packets contain send and receive sequence numbers in the third octet followed by data starting in the fourth octet. The first octet contains a D bit which is used to designate the

originating source of acknowledgments. With the D bit set to zero, (D=0), acknowledgments will come from the gateway. If the D bit is set to one, (D=1), then the acknowledgments must originate at the remote network termination. The normal case is for D=0, and the gateway sends acknowledgments. The M bit in the third octet is used to indicate the final frame in a sequence. Control packets are used to communicate commands and responses between peer-level entities. Commands and responses are defined by primitives which are coded into the packet-type field. These primitives are the backbone of the management of the layer 3 entity which implements the error handling, flow control, and sequencing functions. Just as it was with the I.451 protocol for the D-channel, most commands require additional information. This additional information is appended to the packet immediately following the packet-type identifier. A complete description of the primitives and related information can be found in CCITT's X.25 standards.

6.4.2 Step 4: DDN Half-gateway Module

The DDN half-gateway module consists of four layers. The protocols at these four layers do not correspond to the standard OSI model layers. In an internet environment, protocols at layers 1 and 2 are referred to as network protocols, the IP is called a gateway protocol, and TCP is referred to as the host protocol. Although these protocols do not conform to OSI standards, for reasons of clarity reference will still be made to the OSI layers: physical layer, data link layer, network layer, and transport layer. The functional decomposition of the DDN

half-gateway module is shown in Figure 6.20. There is one very distinct difference between the DDN half-gateway module and the ISDN half-gateway module and that is in-band signaling versus out-of-band signaling. The DDN protocols handle signaling information that is inter-mingled with data, where as ISDN uses a separate D-channel for signaling information. The following sections will explain the functions of each layer and the protocols implemented at each layer.

6.4.2.1 Physical Layer of the Defense Data Network

The Defense Data Network employs the X.21 standard at the physical interface. X.21 specifies a connection similar to the RS-232-C connection except X.21 has only 15 pins compared to 25 with the RS-232-C. Of these 15 pins only 8 are used and they are shown in Figure 6.21. X.21 is a significant improvement over RS-232-C because improved digital logic circuits have removed the need for separate wires for every signal. X.21 is responsible for controlling the transmission and reception of information from the physical medium. The X.21 protocol must also communicate with the data link layer protocol, X.25. X.21 and X.25 cooperate to achieve the lower layer functions of the DDN.

6.4.2.2 Data Link Layer of the DDN

The data link layer protocol is the same for both DDN and ISDN's B-channel. Although both ISDN and DDN implement X.25 at the data link layer, the protocols are not identical. The X.25 protocol has several variables that could make DDN's implementation of X.25 clearly different than the implementation on ISDN's B-channel. Some of these differences might be in frame

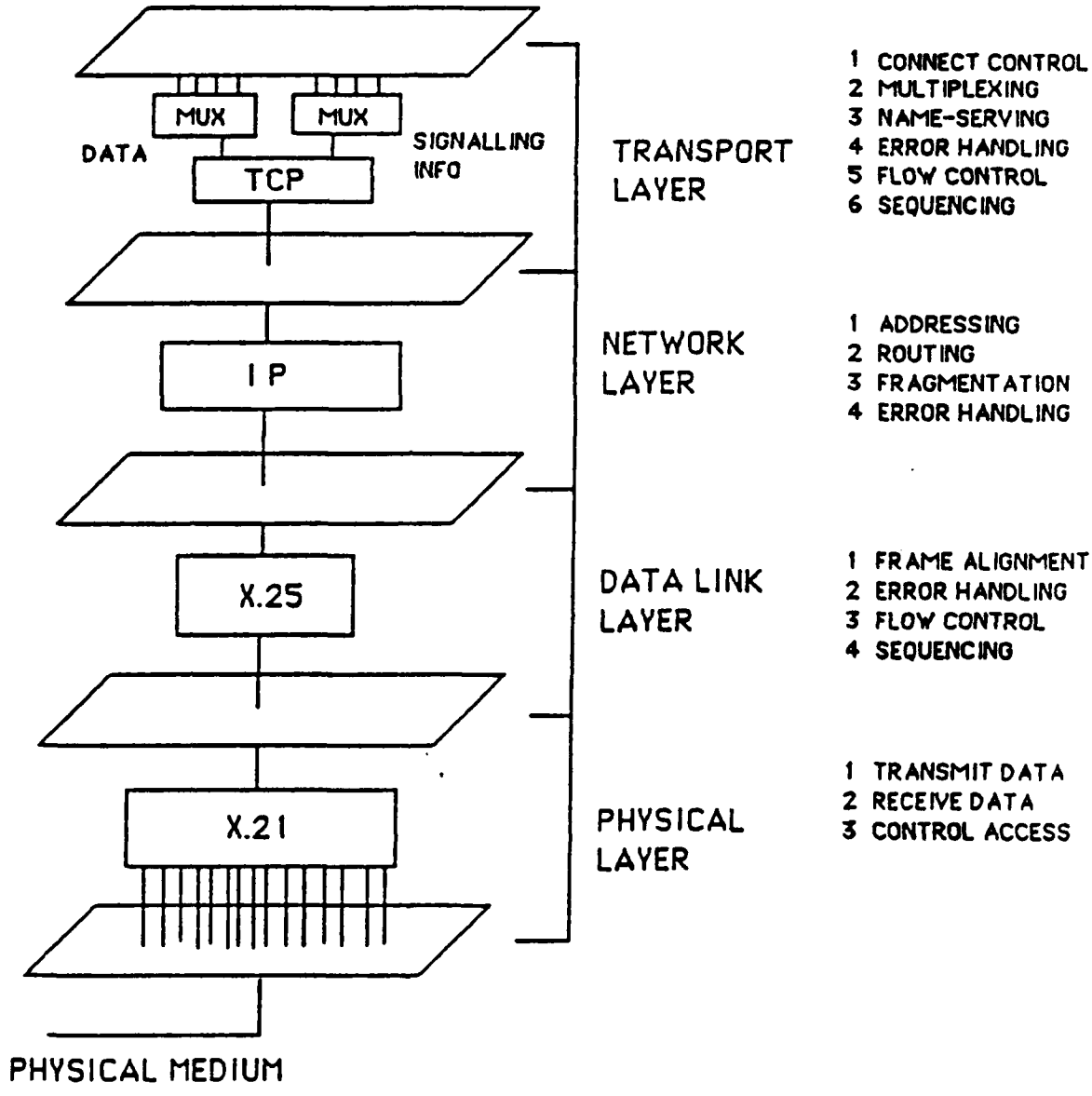


Fig. 6.20 Functional decompostion of DDN half-gateway module

SIGNAL NAME	FUNCTION
GROUND	
COMMON RETURN	
TRANSMIT	Transfer information to network
RECEIVE	Accept information from network
CONTROL	Provides control information
INDICATION	Provides indications
SIGNAL ELEMENT TIMING	Provides bit timing
BYTE TIMING	Provides byte timing

Fig. 6.21 X.21 signal names and their functions.

length, timing functions, or windowing used for flow control. It should be clear that these two implementations of X.25 are different in the way that they communicate with the adjacent layers. DDN's implementation of X.25 must communicate with X.21 at the physical layer and with the internet protocol (IP) at the network layer. Similarly, ISDN's implementation of X.25 must communicate with the I.430 or I.431 protocol at the physical layer and with X.25 layer 3 at the network layer. Nevertheless, for the scope of this report we can assume that the basic functions are the same. The frame structure of the X.25 protocol is shown in Figure 6.18 and its functions are discussed in section 6.4.1.4.

6.4.2.3 Network Layer of the DDN

The Defense Data Network uses the internet protocol (IP) as the network layer protocol. IP is defined in the DoD RFC 791. As stated before, the internet protocols are not modeled according to OSI standards. Because of this, IP will perform a different set of functions than those described for the ISDN layer 3 protocols. The main functions of IP are listed below:

1 addressing and routing,

2 fragmentation and reassembly,

3 error detection and recovery, (ICMP).

The first and most important function of the IP is to deliver packetized data, commonly called datagrams, from a source to its proper destination. The purpose of IP is to determine an appropriate route through gateways and intermediate systems to send the datagrams so they end up in the right place. Actually,

this route is determined one step at a time from gateway to gateway. The IP checks the destination address of the datagram which is part of the internet protocol header. This header is shown in Figure 6.22. If IP is able to deliver the datagram directly to its destination it does just that. Otherwise, IP looks up the address in a routing table and then sends the datagram to the appropriate gateway to forward the datagram. The receiving gateway then performs a similar routing function to direct the datagram. In the event that this destination address is not in the routing table IP sends the datagram to a pre-determined default gateway. For most practical purposes it can be assumed that the DDN/ISDN gateway will be a default gateway. Once the packet has reached ISDN, ISDN will implement its own internal routing functions to deliver the datagrams to the proper destination. Description of ISDN's routing function is beyond the scope of this report. Currently most of the available ISDN standards refer to the user-network interface. It is expected that CCITT's 1988 version of ISDN standards will have more information related to network operation. Figure 6.22 shows that the internet header contains two 32 bit addresses, one source and one destination. Internet addresses are separated into three classes, A, B, and C according to the size of the network with class A being the largest. The Arpanet is in class A and therefore discussion in this report is limited to this class of addresses. Class A addresses use 7 bits to identify the network and 24 bits to identify the host on that network. Most of the fields in the internet header are self-explanatory. If more

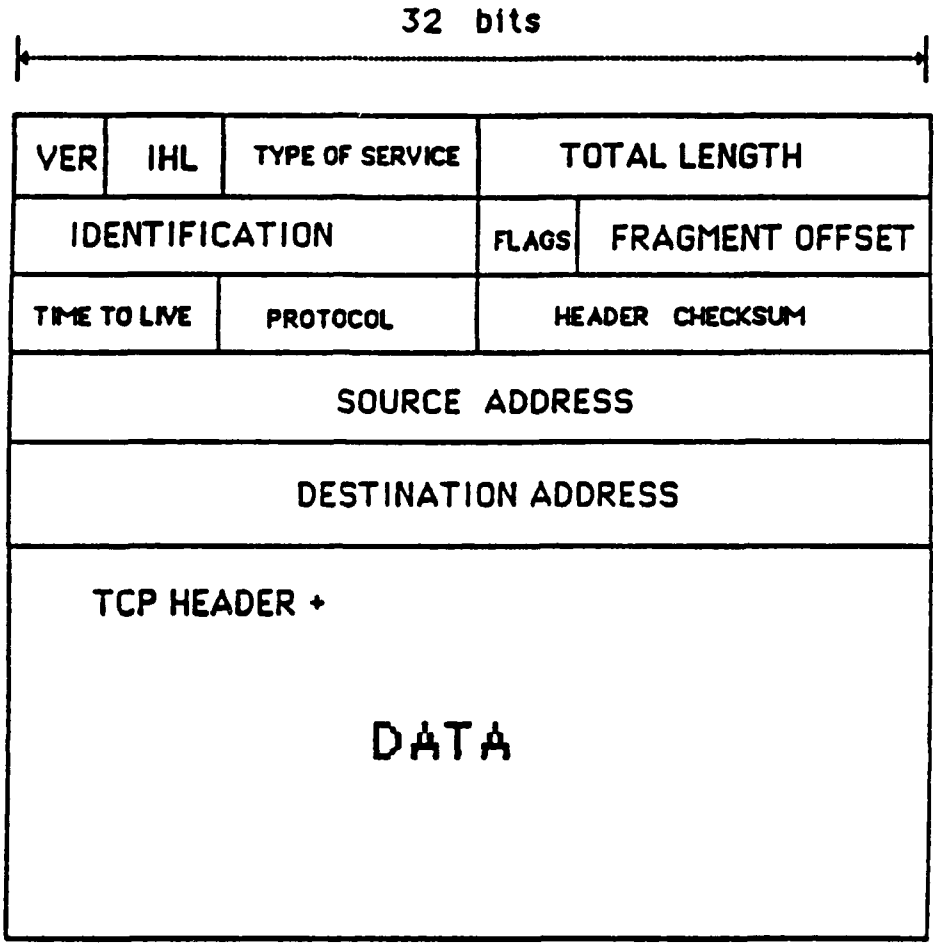


Fig. 6.22 Internet Protocol frame structure

detail is desired, a thorough explanation of the header is given in RFC 791. Some of the more significant fields which deserve mentioning are the header checksum, identification, fragment offset, and time to live fields. Every time an IP receives a datagram it computes a very simple checksum on the information in the header. This checksum is performed only on the IP header, not on the data. This is done because the IP header changes each time it is processed. The time to live field contains a number that is decremented each time an IP processes the datagram. When this number reaches zero the datagram is discarded. This is used to prevent packets from being sent from gateway to gateway without ever reaching the proper destination. The identification and fragment offset fields are used in reassembling datagrams that have been fragmented. Fragmentation is sometimes necessary when one of the intermediate networks or gateways is unable to handle large datagrams. This should not be a problem when sending datagrams to ISDN, but is still a necessary function to be performed by the integrated gateway. When IP detects an error it calls upon the support of the Internet Control Message Protocol (ICMP). ICMP is an error reporting protocol, but it does not make IP reliable. The ICMP only reports those errors that are detected by the IP such as: fragmentation needed, route failure, or unreachable network. An example of route failure is when the time to live has expired. ICMP sends notification that the route taken was the wrong one and then IP will decide on an alternative route.

6.4.2.4 Transport Layer of the DDN

The DDN uses the Transmission Control Protocol (TCP) as the transport layer protocol. This protocol is defined in the DoD RFC 793. TCP is designed to provide highly reliable end to end data communications.. The functions performed by TCP are:

1 connection control,

2 multiplexing,

3 name serving,

4 error handling,

5 sequencing,

6 flow control,

7 precedence and security.

TCP is responsible for keeping track of multiple connections at the same internet address. IP interprets the internet address and delivers it to the host layer protocol, TCP. From this point, TCP must be able to distinguish between many different applications that all use the same internet address. TCP keeps track of different applications by assigning port numbers to them when a connection is established. TCP is then able to send multiplexed datagrams from several applications to IP. IP is not concerned with this port number, but instead is merely concerned with delivering the datagram to the proper destination address. TCP tells IP what the destination address is for every datagram. Along with the datagram and destination address TCP includes its own header that is placed at the front of the datagram. IP treats the TCP header as if it were data. The TCP header is shown in Figure 6.23. This header contains a source and

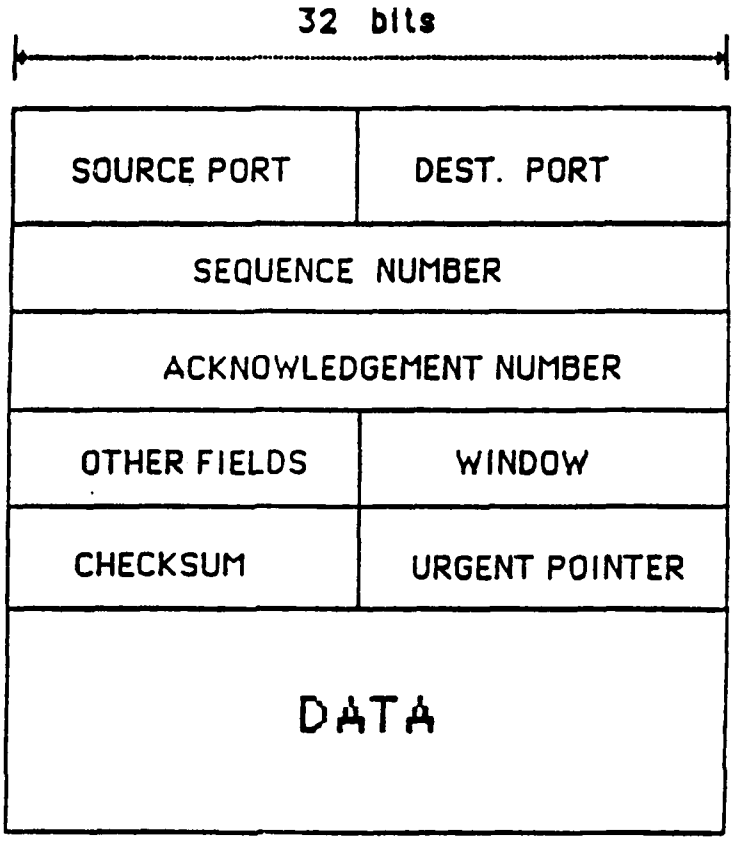


Fig. 6.23 Transmission Control Protocol frame structure

destination port number. When a user requests a service from a remote host, TCP first takes on the responsibility of establishing a connection. TCP will assign a local port number for the application and send an open request to the remote host with the port number of a "well-known socket" stored in the destination port number field. This "well-known socket indicates to the remote host what type of application is being requested. For example the File Transfer Protocol is supported by socket number 21. A list of "well-known socket numbers" for the various applications protocols can be found in the DoD RFC 1010, Assigned Numbers. After the remote host receives this open request, the two ends swap port numbers and after some back and forth signaling, the connection is established and is ready for the transfer of data. TCP is also responsible for the sequencing of data at the two ends. The TCP header contains a 32 bit sequence number. Sequence numbers are assigned by octets, not by frames as was the previous case with X.25. So if frames are assembled with 500 octets, the sequence numbers would be 500, 1000, 1500, and etc. The acknowledgment number is used to acknowledge to the sender the highest sequence numbered octet that was received correctly. The window field is used to indicate the amount of data that can still be accepted without waiting. This is how TCP implements the flow control function. When the window field is set to zero, transmission is halted until an acknowledgment is returned with a window value that is greater than zero. The urgent field is used to tell the sender to proceed to a higher numbered frame or octet. This prevents

retransmission of frames that were received correctly and helps improve throughput. The TCP also performs a checksum on the data and the addresses that it passes to IP. This checksum is what makes TCP reliable. TCP not only verifies that the data is correct, but also that the source and destination addresses it assigns are correct too. The other fields in the TCP header are beyond the scope of this report. A complete description of the TCP header can be found in RFC 793. TCP also makes use of the

over the next few years. It is expected that many vendors will help meet this demand by supplying half-gateway modules as single-board-computers (SBC's). These SBC's should be designed to fit into the interface slots of a commonly used mini-computer or micro-computer. This will undoubtedly save many gateway design engineers time and headaches, but still there is the decision of which micro-computer or mini-computer to use. There are many factors to consider when making this choice such as: What is the throughput capacity of the system? What type of software, operating system, is needed? What type of software and hardware is available for implementing the translator module? How will this computer facilitate interfacing the two SBC half-gateway modules? These questions will be easier to answer once vendor participation is increased in the area of internetworking.

6.6 Step 6: Design the Translator Module

Once the DDN and ISDN half-gateway modules have been built as described in section 6.4, a translator module must be designed to interconnect the two half-gateway modules. The translator module is needed to make the conversions between the different network characteristics. The functions of the translator module are as follows:

1 address translation,

2 routing,

3 flow control, buffering, and rate adaption

4 congestion control,

5 protocol conversion,

6 real-time response,

7 performance monitoring and statistics.

Figure 6.24 diagrams the entire DDN/ISDN gateway and shows the function of each component. This diagram along with the explanation of the translator module functions should clarify the overall operation of the gateway.

6.6.1 Address Translation

The translator module must be able to translate the internet address into an ISDN address and vice versa. These two addresses are completely different. The internet address is a 32 bit address and the ISDN address is a 55 decimal digit address. The ISDN address is broken down into a 15 digit ISDN number and a 40 digit sub-address. The ISDN number is used to identify a particular S or T reference point of the ISDN user-network interface. The sub-address is transferred through the network transparently to the network layer protocol. In addition to the internet 32 bit address is a 12 bit channel identification which is also essentially part of the address used to identify the user application. It is the responsibility of the translator module to be able to interpret one type of address and generate the other. It is likely that this will be done by some type of large scale name-server. One problem that has not been cleared up yet is how the ISDN number will be abbreviated in the address fields of the LAP-D and X.25 protocols. This is currently being studied by CCITT and a solution should be presented in the 1988 version of the I-Series Recommendations.

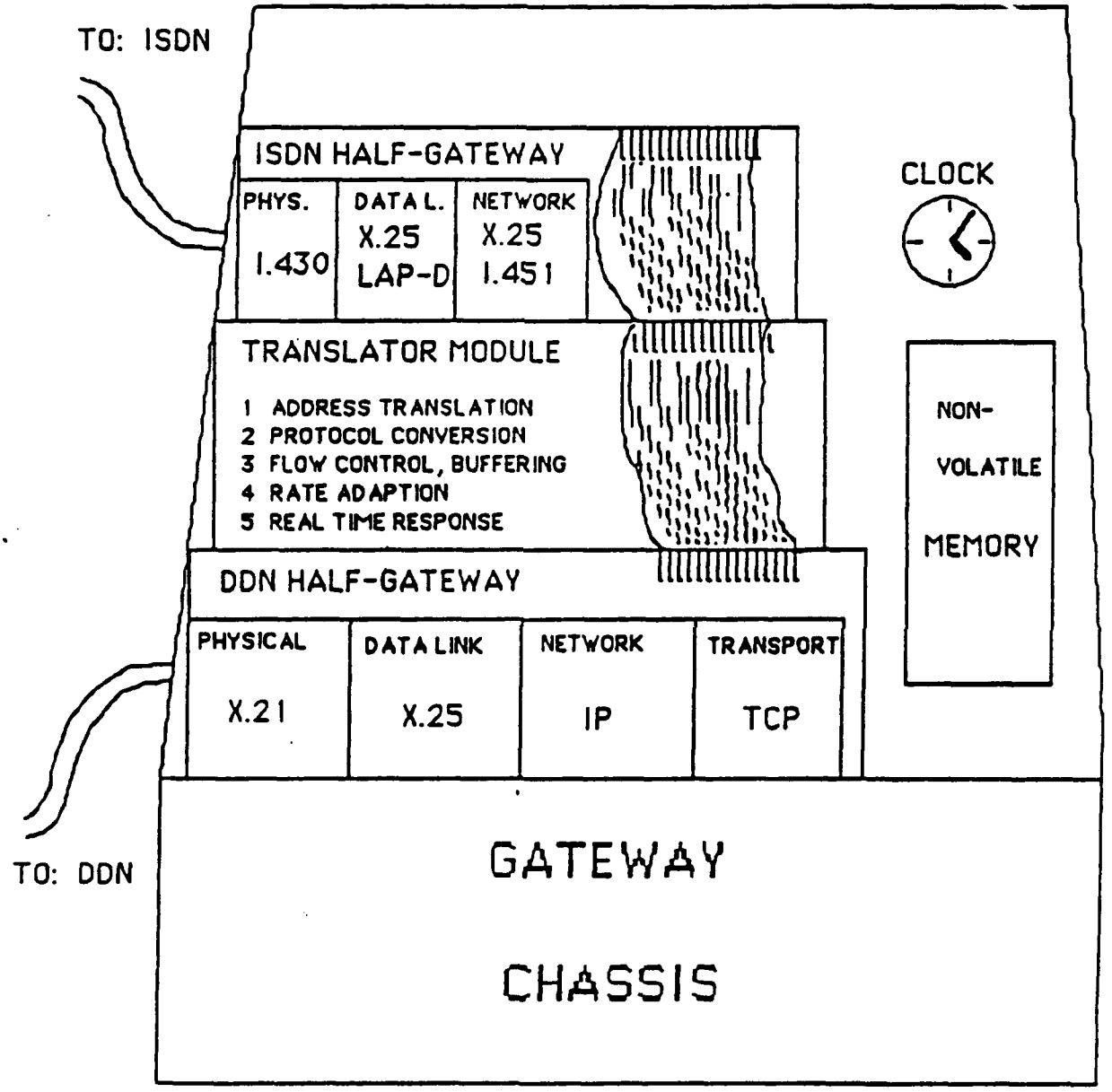


Fig. 6.24 Gateway chassis and internal components: DDN half-gateway module, translator module, ISDN half-gateway module, clock, and non-volatile memory

6.6.2 Routing

The gateway must be able to determine a proper route to direct datagrams to their destinations. When packets are being sent from DDN to ISDN routing is not a serious problem because the internal workings of ISDN will route the data to the right destination node. On the other hand, when packets are being sent from ISDN to DDN the gateway must route the data to the proper network. In order to do this the gateway must maintain a routing table for IP to use in directing datagrams.

6.6.3 Flow Control , Buffering, and Rate Adaption

Flow control is an essential function of the gateway, and a large part of this responsibility lies within the translator module. Both half-gateway modules have their own flow control mechanisms, but the translator module must also implement flow control between the two half-gateway modules. To do this the translator must communicate simultaneously with the flow control mechanisms on both sides of the gateway. Because DDN and ISDN have different data rates the translator module must buffer information as it comes in and control the flow of data in order to prevent the gateway or the DDN from being overloaded.

The translator module must be able to adapt the data rate of DDN to the data rate of ISDN and vice versa. The data rate used on the DDN is 56 Kbps and the data rate used on ISDN's B-channel is 64 Kbps. The procedure for adapting the data rates to comply with ISDN's 64 Kbps is defined in Recommendation I.460. The reverse procedure is equally important. The translator must be able to accept ISDN data at 64 Kbps and rate adapt this to 56

Kbps for transmission on the DDN. There exists the possibility that the data coming from ISDN has been rate adapted at a remote site. In this case the gateway must be able to distinguish which data is real and which data is not real. In order to do this the gateway must perform the reverse of the mapping procedure used in the original rate adaption. This process can be accomplished cooperatively by the translator module and the network layer protocols of the ISDN half-gateway module.

6.6.4 Congestion Control

In the event that the gateway becomes congested with too much information, the gateway must indicate to neighboring gateways that an alternate route should be taken if possible. The gateway must also indicate when it is again ready to accept more data.

6.6.5 Protocol Conversion

Protocol conversion is probably the single-most important function of the translator module. This is also the most complicated of the translator module functions. Protocol conversion is a process of mapping states in one protocol to the states in another protocol. The states of a protocol are described by a Finite State Machine. These finite state machines can become very complex. The conversion process in the DDN/ISDN gateway is especially complex because the top layer protocols of the gateway are dissimilar in both function and implementation. This dissimilarity is acutely severe because ISDN implements two separate protocols, X.25 on the B-channel, and I.451 on the D-channel. TCP, the top layer protocol in the DDN half-gateway

module, not only performs the functions that are jointly executed by X.25 and I.451, but also performs functions like name-serving that are not supported by X.25 or I.451. From this it is clear to see that mapping the states between the two finite state machines is a difficult task. It is likely that a perfect mapping of states will not exist. This might bring about some soft-mismatches, but hard-mismatches should be avoidable. Soft-mismatches relate to errors that are acceptable and do not prevent the gateway from operating. Hard-mismatches on the other hand cause errors that can not be accepted and prevent the gateway from operating.

6.6.6 Real-Time Response

The translator module must be able to handle packets in real-time in order to prevent unacceptable delays in the transmission of data. The translator module must be able to handle the event timing functions of the DDN and ISDN. Both networks have functions that require timed responses. The translator module must be able to communicate with both networks and give acknowledgments within the designated time frame to prevent erroneous errors from occurring.

6.6.7 Performance Monitoring and Statistics

The translator module should record statistical information about the traffic through the gateway. This information can be used to improve the performance of the gateway through modifications, but equally important this recorded information can be used for billing purposes. Billing will be provided by the vendor who supplies the ISDN service, but this billing will

be for the entire interface or node. The gateway can record information that will show which users accessed the ISDN service, thus making it possible to bill each user accordingly.

6.7 Step 7: Testing the Integrated Gateway

Testing the integrated gateway and bringing it up to an operational level could be as difficult a task as designing it in the first place. The functions of the gateway should be added in slowly first starting out with basic transfer of data without any additional functions. After the gateway is operational, functions should be tested one at a time starting with building up and tearing down connections. Once all of the functions of basic service are operating properly, the gateway can be installed for limited use and further real-time testing. Additional functions such as those contained within the quality of service parameters can be tested and included later. ISDN is expected to expand its range of services once it becomes established. When this happens, the gateway should be able to be modified to take full advantage of the ISDN.

6.8 Limitations of the DDN/ISDN Gateway

There exists the possibility that the DDN/ISDN gateway might impose noticeable delays in the transfer of data. This is not something that is unique to the case of the DDN/ISDN gateway, but is common to all gateways. These delays come about from extra processing time, error recovery, and congestion within the gateway. It is important that the translator module record performance statistics so improvements can be made. The delays caused by processing time are greater in this type of gateway as

opposed to a bridge. A bridge only covers the first two layers while the DDN/ISDN gateway covers four layers on the DDN side and three layers on the ISDN side. Processing at these extra layers is more expensive in terms of time, but increases reliability. This extra processing time at the DDN/ISDN gateway may well be worth not having to send data through a series of networks and gateways, and in that respect response time may actually be reduced. Of course, much of this depends upon the performance of the ISDN itself.

6.9 Conclusions and Recommendations

There is a definite need to internetwork the Defense Data Network and the Integrated Services Digital Network. ISDN will provide the DDN with access to networks world-wide without the problems of communicating through multiple intermediate networks and gateways. Internetworking DDN and ISDN is achieved by designing and building an integrated gateway. This report has contributed a design of the functional architecture of such a gateway. Critical design issues and unresolved problems have also been identified. The detailed design of the gateway should be done by a group of individuals who have expertise in data network communications. Specifically, some individuals should be deeply involved with the Defense Data Network and some should be deeply involved with the Integrated Services Digital Network. There should also be a mix of both hardware and software engineers. As mentioned before, it is likely that vendor's will supply the half-gateway modules which will greatly reduce the difficulty of gateway design. At the present time there are not

enough ISDN standards to complete the design of an integrated gateway. CCITT is expected to release a new version of ISDN standards in 1988 that should shed light on all of the haziness about ISDN. After these standards are released, ISDN should move rapidly into its marketplace. The first ISDN customers will be large businesses, and after gateway technology is developed the Department of Defense will enter into the market. The DDN/ISDN gateway will be able to provide users with transparent, reliable, end-to-end digital communications from one end of the world to the other. The most significant limitation imposed by the gateway is the requirement for protocol compatibility at the upper layers on the two end systems. Although this may seem very limiting, it is actually a very practical assumption. Given the many advantages of internetworking DDN and ISDN, it is recommended that research in the area of gateway development be continued in order to stay abreast of the changing technology of data communications.

7.0 CONCLUSIONS AND RECOMMENDATIONS

ISDN has reached an evolutionary stage where it is essential for the U.S. Army to begin taking steps to implement this new communications technology. The global development of ISDN has moved very rapidly during the past few years and can be expected to move even faster during the 1988 to 1990 period. Throughout this report we have discussed many of the unique aspects of an ISDN, and the benefits brought about by coordinating this technology with existing Army networks. Generalized as well as detailed inspections of the approaches to internetworking with ISDN have been developed and presented.

An Integrated Services Digital Network can be thought of as a world-wide standard for modern communications that provides the high reliability of end-to-end digital connectivity and integrates all types of services into one network for efficient use of bandwidth. Standards for ISDN are being developed by CCITT and are structured around the Open Systems Interconnection reference model. Current ISDN standards are available in the 1984 version of the I-Series Recommendations, CCITT Red Book. These standards are designed to be able to cross international boundaries without conflict, thus creating a unified global communications standard. CCITT will publish another set of ISDN standards in 1988. These standards should fill most of the gaps that currently exist, and should also open new doors for the expansion of ISDN research into areas such as Broadband ISDN and the use of fiber-optics. Many years of research, testing, growth and expansion are required in order to realize the full potential

of an ISDN. The development of an ISDN is without doubt an evolutionary process. The early stages of ISDN are going to be devoted to providing just the basic services to very large customers. Over time, feedback from these first customers will influence the evolutionary course of ISDN. Because the Department of Defense will be one of ISDN's largest customers, it is critical that the DoD take an active role in the development of ISDN within the marketplace.

Throughout this report we emphasized how an ISDN can enhance the existing Army communication networks. Many of the advantages are clear when one considers the impact of ISDN on all types of communications throughout the world: international standardization, integrating services, highly reliable digital connectivity, etc. Initially, the primary service to be used by the Army will be packetized data communication, and therefore many of the services of ISDN will go unused, but as ISDN moves forward, it may become practical for the Army to utilize other ISDN services. Currently though, the primary advantage of internetworking Army networks with ISDN is standardization. As discussed in chapters 4, 5, and 6, the use of ISDN as a neutral network eliminates the need to spend time and money for the development of gateways for each and every connected network. The short term expense of developing ISDN gateway technology will prove to be much less costly than the expense of waiting and ignoring the fact that the future of data communications is headed toward a global ISDN.

The generalized approach to internetworking two incompatible networks is presented in chapter 4. Four approaches were presented, each one depending on the level of incompatibility. Essentially, Approach 3 is the most practical for real world implementation, but also the most difficult. This approach is to design and build an integrated gateway to implement the functions necessary to bridge the gap between the incompatible network protocols. This integrated gateway contains two half-gateway modules and a translator module. The half-gateway modules implement the lower layers of each network and the translator is used to make necessary conversions to link the two half-gateway modules. Approach 4 is just a special case of Approach 3 and uses a network standard to implement one of the two half-gateway modules. Chapters 5 and 6 expand on the generalized approach presented in chapter 4 to the specific problems of internetworking ISDN/LAN and ISDN/DDN. Several current uncertainties which affect the specific design process were identified. It is anticipated that most of these problems will be resolved by the 1988 standards.

Although this report might lead one to believe that designing a gateway is a simple task of collecting information and comparing incompatibilities, this is not the case. Gateway design is very complicated, and the problem must be attacked by a team of skilled and knowledgeable engineers. Gateway design involves development of both hardware and software and by no means is a trivial task. As mentioned earlier in this report, vendor participation in the development of gateway technology

will be of tremendous help in the future as the need for this technology becomes more widespread.

Over the next few years ISDN technology will change the world of communications drastically. It is recommended that the Army take an active role in developing the future of ISDN within the U.S. and around the globe. Waiting for ISDN to mature without participation during the early stages and failure to plan for the future could result in an ISDN that falls short of the expectations of the Department of Defense.

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